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Preparatory work for the Environmental Effect Study on the Euro 5 step of L-category vehicles

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Abstract
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In principle, a vehicle should be clean and energy efficient in each and every operation point. In particular, vehicles belonging to the L-category family were tested over the current legislative test procedure, according to the future legislation contained in Regulation 168/2013 [1] and during a wide open throttle test to assess the maximum performance of the vehicles (max power and torque). Several engine load variables were logged during the experimental testing: Second-by-second mass emissions of carbon dioxide, fuel consumption, power and torque at the wheel, throttle position, etc. The use of load variables is especially useful when on-road driving has to be compared to the legislative testing conditions. The new test cycle proposed for Euro 5 type approval, the Worldwide harmonized Motorcycle Test Cycle (WMTC) proved to be better than the present driving cycle in terms of quantity, quality and dynamics of testing/sampling points. The results related to the monitored load variables are vehicle specific and it was not possible to identify a single all-purpose fitting variable capable of describing engine load conditions during the test. Nevertheless the set of variables investigated in this work are promising and will be used as underpinnings for the Effect Study.

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Executive summary

Policy context

The legislation concerning the type approval of mopeds and motorcycles is under major revision by the European Commission. Regulation EU 168/2013 [1] (Reg.168, hereafter) and Regulation EU 134/2014 [2] (Reg.134, hereafter) on the approval and market surveillance of two- or three-wheel vehicles and quadricycles set out new propulsion and environmental requirements in two stages (Euro 4 and Euro 5) with the second stage (Euro 5) being mandatory for new types of vehicles as of 01 January 2020.

Based on future available data, an environmental effect study required by Reg. 168 (Article 23(4) and 23(5)) should provide additional underpinning for the Euro 5 step (main Euro 5 Effect Study) through modelling, technical feasibility and cost-effectiveness analysis based on the latest available data. The Directorate General for Internal Market, Industry, Entrepreneurship and SMEs (DG-GROWTH) of the European Commission has requested the Joint Research Centre to conduct a Pre-Study as input to the main Effect Study.

A new paradigm, introduced by the European Commission, has represented the backbone of the Pre-Study: the vehicles should be clean and energy efficient in each and every operation point that is allowed by the vehicle (regardless of the effective use in real life).

The present report describes the outcome of the Pre-Study carried out by the JRC.

Main findings

Engine load variables

Several engine load variables were theoretically considered and experimentally measured during the campaign: mass emissions of carbon dioxide, fuel consumption, power and torque at the wheel, throttle position, manifold absolute pressure, and position of the accelerator.

These variables have been then compared to the torque at the wheel, considered to be the best proxy for the engine load variable when only vehicle related measurements are possible (whole vehicles are usually available for testing without the possibility of removing the engine and testing it separately on an engine bench test).

The results obtained are vehicle specific and it has not been possible to identify a single variable able to properly describe the behaviour of all the different vehicles. In general, results are better for larger engines (L3e and L7e sub-categories), while mopeds do not display a clear dependence of the torque at the wheel from the other engine load variables.

The most promising variable is the throttle position retrieved from the engine control unit of the vehicle. Nevertheless, this output is available only on medium-high performance motorcycles and recent quadricycles. Alternatively, the fuel consumption may be used.

WMTC assessment

The torque at the wheel variable was assessed against the engine speed over i) the Worldwide harmonized Motorcycle Test Cycle (WMTC), ii) the current driving cycle for type approval (UNECE-R40 [3] and UNECE-R47 [4]) and iii) a maximum power test performed in wide open throttle (WOT) mode. The indicators Quality, Quantity and Dynamics of test/sampling points were used to evaluate the WMTC against the present driving cycle and to compare the driving cycles with the maximum torque curve obtainable during the wide open throttle test. In general the WMTC is better than the UNECE-R40 [3] and UNECE-R47 [4] with larger test/sampling area, and larger torque range covered. In addition, the unsampled area below the maximum torque curve and above the WMTC and present legislative driving cycle was found to be substantial for high performance vehicles with manual transmission and less pronounced or hardly identifiable for vehicles with Constantly Variable Transmission (CVT) and limited speed such as mopeds. However, this unsampled area may represent a significant fraction of the engine operating conditions during on-road operations, leading to a potential mismatch between the real world environmental and efficiency performance and those measured according to the legislative procedure.

Related and future JRC work

During the drafting of the present work (Pre-Study), as a consequence of a call for tender the Euro 5 Effect Study was contracted to an external consortium by DG-GROW. As detailed in the technical specifications of the call for tender, the JRC will contribute to this main study by performing a large part of the planned tests at the VELA laboratories of the Sustainable Transport Unit, Institute for Energy and Transport. Moreover, the Effect Study will partly rely on the results of the present Pre-study.

Quick guide

Exhaust emissions from vehicles for type approval purposes are tipically measured during prescribed driving cycles (speed trace) with the vehicle running on a roller bench. The exhaust gas from the vehicle is first diluted with fresh air (mainly to avoid water condensation) and then a sample of the diluted exhaust is collected in dedicated tedlar® bags during the whole test. At the end of the test the concentration of regulated gaseous pollutants (total hydrocarbons, carbon monoxide, nitrogen oxides) is measured by means of suitable analyzers. The total amount emitted during the test is then divided by the distance covered by the vehicle to obtain distance specific emission values. The relevant legislation set the upper limit of these distance specific emissions values for type approval purposes. At the moment, neither particulate emissions nor on-road testing are considered for the L-category.

In this study we compare the engine load (capacity to do a certain work) profile of several vehicles recorded over the pre-Euro 5 driving cycles and the new Euro 5 driving cycle (Regulation EU N. 168/2013 [1]). Both these engine load profiles are then compared with the maximum performance the vehicles can achieve in terms of power (and torque) at the wheel.

1. Introduction

1.1 Legislative context

The present document describes the results of the Euro 5 L-category Environmental Effects Pre-Study (Pre-Study hereafter, see Appendix 1), which serves as input for the main Euro 5 L-category Environmental Effects Study (Effect Study, hereafter, see Appendix 2). L-category vehicles include 2- and 3- wheelers as well as quadricycles, such as mopeds, motorcycles, quads and minicars.

Regulation (EU) No 168/2013 [1] (Reg.168, hereafter) and Regulation (EU) No 134/2014 [2] (Reg.134, hereafter) set out environmental requirements for the L-category vehicles to be implemented in two stages, with the second stage (Euro 5) being mandatory for new types of vehicles as of 01 January 2020. This creates a long-term regulatory framework allowing vehicle manufacturers and supplier industry to plan ahead startegies and investments. Based on future available data an environmental Effect Study stipulated in Reg.168 Article 23(4) and 23(5) will provide additional underpinning through modelling, technical feasibility and cost-effectiveness analysis based on the then latest available data. The structure of the Effect Study is detailed in Appendix 2.

In addition, the Effect Study will assess the feasibility and cost-effectiveness of in-service conformity testing requirements, off-cycle emission requirements and a particulate number emission limit for certain (sub-) categories. On the basis of the Effect Study results, the Commission should consider presenting a proposal to introduce these new elements into future type-approval legislation applicable after the stages foreseen in this Regulation.

According to Reg. 168/2013 [1] the Commission shall by 31 December 2016 present to the European Parliament and the Council a report on the following:

(a) The enforcement dates of the Euro 5 stage referred to as in Reg.168, Annex IV;

(b) The Euro 5 emission limits referred to as in Reg.168 Annex VI(A2) and the OBD thresholds as in Reg.168, Annex VI(B2);

(c) Whether, in addition to OBD stage I, all new types of vehicles in (sub-) categories L3e, L5e, L6e-A and L7e-A, shall be also equipped with OBD stage II at the Euro 5 stage and whether OBD stage I should be extended as well to categories L1e and L2e;

(d) The durability mileages for the Euro 5 stage referred to as in Annex VII(A) and the deterioration factors for the Euro 5 level referred to as Annex VII(B), as well as when it will be appropriate to phase out the AMA distance accumulation cycle.

1.2 Scope of the Pre-Study

Up to date, the applicable emission laboratory test cycle (WMTC) is based on a speed profile derived from real-world data obtained from a representative test fleet (motorcycles) operated at typical driving conditions. The assumption on the basis of which the WMTC was defined is that the largest portion of tailpipe pollutant emissions is produced, and most of the energy consumed in engine operation points representing the typical/average use of the vehicle. Consequently, a large share of the high part-load to maximum load area may not be sampled in the emission test, resulting in a **significant mismatch** between type-approval pollutant and energy efficiency test results in comparison to those in actual use and under real-world conditions.

This paradigm has to be shifted to the principle that **an engine has to be clean and energy efficient in each and every operation point under the maximum torque curve**, regardless of the frequency of the operation point during average use. This is anticipated to significantly close the gap between the actual pollutant emissions and energy consumption measured under real world conditions in comparison to the test results in the respective emission laboratory test cycles.

So far, driving cycles of laboratory based tests for road vehicles have been assessed and defined on the basis of vehicle speed. Generally, vehicle speed weakly correlates with engine load, which makes an objective analysis and comparison between the emission laboratory test conditions and representative real-world driving conditions difficult and hardly achievable. In order to succeed with the Euro 5 Effect Study, it is paramount that **the WMTC for other categories than category L3e motorcycles is verified and validated on the basis of engine speed and commonly accepted engine load variables.**

Figure 1 illustrates the power at the wheel of an L3e-A3 motorcycle recorded over different driving cycles: the legislative pre-Euro 5 R40 cycle, the WMTC, and a wide open throttle (WOT) cycle. While, the WMTC test/sampling points cover a larger part-load area (blue) than the R40, the red hatched area under the maximum power curve is still currently not sampled in the emission laboratory tests. It should be investigated how the WMTC and off-cycle emissions measurements in the future can become complementary so to assess at type-approval to what extent each engine operation point corresponds to low emissions and if the energy efficiency is optimized.

In theory, multiple engine load measurements are possible such as: the output torque of the engine at the wheel(s), or with a torque sensor on the crankshaft; the indicated mean effective pressure (IMEP) or brake mean effective pressure (BMEP) directly with a pressure transducer fitted in the combustion chamber or in the spark plug; the injected fuel mass or the associated electronic injector opening signal; the induction air mass with a mass air flow sensor or indirectly with a manifold absolute pressure sensor; the tailpipe CO_2 emissions. All these different engine load measurement methodologies have practical pros and cons which should be assessed and listed and the preferred option should be identified. This is the justification for the research and development of a commonly applicable engine load variable of practical use.

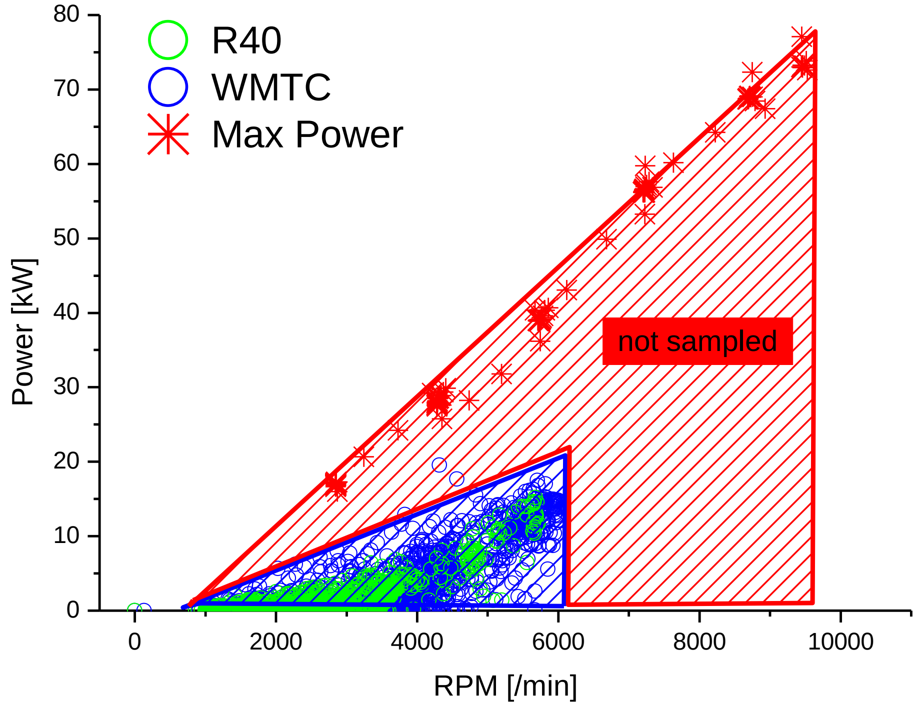


Figure 1. Example of maximum power curve and part-load areas for an L3e motorcycle. R40 = UNECE-R40 driving cycle [3] (conventional motorcycle test cycle up to Euro 3, green markers); WMTC = World-harmonized Motorcycle Test Cycle (see Reg.134, blue markers). Max Power: Wide Open Throttle test cycle (also known as maximum power).

1.3 The L-category family

The following Table 1 describes the vehicles falling in the L-category. It is a wide range of vehicle types, from power assisted bicycles and small scooters (mopeds) to motorcycles, tricycles and quadricycles as quads and minicars.

Table 1. The family of L-category vehicles.

L1e		L2e	L3e	L4e	L5		L6e		L7e		
Light two-wheeled vehicle		***Three-wheel moped***	***Motorcycle***	***With side car***	***Tricycle***		***Light quadricycle***		***Heavy qudricycle***		
L1e-A *Powered cycles*	**L1e-B** *Moped*	**L2e**	**L3e**	**L4e**	**L5e-A** *Tricycle*	**L5e-B** *Commercial tricycle*	**L6e-A** *Light quad*	**L6e-B** *Light quadrimobile*	**L7e-A** *Heavy on-road quad*	**L7e-B** *Heavy all terrain quad*	**L7e-C** *Heavy Quadmobile*
		L2e-P 	L3e-A1 	L4e-A1 				L6Be-P 	L7e-A1 	L7e-B1 	L7e-CU 
	Limited speed 	L2e-U 	L3e-A2 	L4e-A2				L6Be-U 	L7e-A2 	L7e-B2 	L7e-CP 
			L3e-A3 								
≤50cc, ≤25 km/h, 250W--1kW	≤50cc, ≤45 km/h, <4 kW	≤50cc, ≤45 km/h, <4 kW, ≤270 kg	<= 11 kW, A2: <=35 kW		3W, <1000 kg,	3W, <1000 kg, max 2 seats, V 0.6m^3	<4kW, ≤425 kg, ≤45 km/h (D, G)	<6kW, <425 kg, ≤45 km/h (D, G)	<15kW, ≤450 kg	W/G<6, ≤450 kg	P: ≤450 kg, U: ≤600 kg, (D, G)

2. Engine Load Variables

Note to the reader:

This Chapter has been written by researchers in the field of exhaust emissions from motor vehicles and it is not meant to be an exhaustive engineering description of the topic “Engine load variables”. The reader can found dedicated material in the literature. This Chapter’s content is therefore instrumental to the scope of this Report that connects some environmental performances with propulsion parameters (such as torque and power at the wheel). In particular, we focused on variables that are easy to measure (i.e., non-intrusive installation of devices) in a typical emission laboratory with no or little intervention on the propulsion unit or on the electronics of the vehicle.

2.1 Introduction to load variables

“Engine Load" is a commonly used term which however is not clearly defined and that can have different meanings depending on the context.

As well known, the output of any internal combustion engine is work. Therefore, in more general terms, the load of an engine can be defined as how much demand is placed on the engine, i.e. how much mechanical work is required to the engine. In other words, the load is directly linked to the output of the engine which is the power of the engine (work done per unit of time).

In an internal combustion engine, the work is done by pressurized gas moving a piston and it is given by:

$$W = \int PdV$$

where P is the pressure of the gas and dV is the volume change.

Two other definitions of work are typically used for engines. The ***indicated work*** is obtained by measuring cylinder pressure and plotting it against volume to obtain the actual cycle representation (the so-called indicator card). Integration of the resulting closed curve gives the indicated work. The ***brake work*** is obtained by measuring shaft torque and converting it to power. The difference between indicated work and brake (or shaft) work consists in losses due to mechanical friction and parasitic loads on the engine (such as the air conditioning compressor, oil pump, alternator, etc.). Brake work (w_b) and indicated work (w_i) are related by:

$$w_i = \frac{w_b}{\eta_m}$$

where η_m is the mechanical efficiency of the engine

The power at any working point of the engine is calculated from the torque and engine revolutions:

$$P_e = M_d \cdot \omega = M_d \cdot 2 \cdot \pi \cdot n$$

where P_e is the effective power and M_d is the torque of the engine, and n is the number of engine revolutions.

The mean effective pressure is an artificial pressure which when multiplied by the displacement gives the work. It is useful in comparing performance of different engines.

The mean effective pressure is given by:

$$p_{me} = \frac{M_d \cdot 2\pi}{V_H \cdot i}$$

where M_d is the torque of the engine, i the number of working cycles per revolution (0.5 in the case of four-stroke engines, 1 for two-stroke engines), and V_H total swept volume of the engine.

Similarly the Indicated mean effective pressure (**IMEP**) and brake mean effective pressure (**BMEP**) are:

$$imep = \frac{w_i}{v_d}$$

$$bmep = \frac{w_b}{v_d}$$

where v_d is the displacement of the engine.

The effective efficiency of the engine is the power output divided by fuel input:

$$\eta_e = \frac{P_e}{\dot{m}_k \cdot H_u}$$

where $\dot{m}_k$ is the admitted mass of fuel per unit of time and H_u is the net calorific value of the fuel.

From the above equations, it appears clearly that the power of the engine is proportional to the mass of fuel mass rate.

In addition to the general definition of engine load given above, there are also specific definitions in the On-Board Diagnostics regulations (see SAE standard J1979: E/E Diagnostic Test Modes): the calculated load value (CLV) and the absolute load value:

Calculated LOAD Value (PID 04)

The OBD regulations previously defined CLV as:

(current airflow / peak airflow @sea level) × (BARO @ sea level / BARO) × 100%

Various manufacturers have implemented this calculation in a variety of ways. The following definition, although a little more restrictive, standardizes and improves the accuracy of the calculation:

LOAD_PCT = [current airflow] / [(peak airflow at WOT@STP as a function of rpm) × (BARO/29.92) × SQRT(298/(AAT+273))]

Where:

- PCT stands for "percent"
- STP = Standard Temperature and Pressure = 25 °C, 29.92 Hg BARO, SQRT = square root
- WOT = wide open throttle, AAT = Ambient Air Temperature and is in °C

Characteristics of LOAD_PCT are:

- Reaches 1.0 at WOT at any altitude, temperature or rpm for both naturally aspirated and boosted engines.
- Indicates percent of peak available torque.

- Linearly correlated with engine vacuum
- Often used to schedule power enrichment.
- Compression ignition engines (diesels) shall support this PID using fuel flow in place of airflow for the above calculations.

Absolute Load Value (PID 43)

The absolute load value has some different characteristics than the LOAD_PCT. This definition, although restrictive, standardises the calculation. LOAD_ABS is the normalised value of air mass per intake stroke displayed as a percent:

LOAD_ABS = [air mass (g / intake stroke)] / [1.184 (g / intake stroke) × cylinder displacement in litres]

Derivation:

- air mass (g / intake stroke) = [total engine air mass (g/sec)] / [rpm (revs/min) × (1 min / 60 sec) × (1/2 # of cylinders (strokes / rev)],
- LOAD_ABS = [air mass (g)/intake stroke] / [maximum air mass (g)/intake stroke at WOT@STP at 100% volumetric efficiency] × 100%.

Where: STP = Standard Temperature and Pressure = 25 °C, 29.92 in Hg (101.3 kPa) BARO,

WOT = wide open throttle.

The quantity (maximum air mass (g)/intake stroke at WOT@STP at 100% volumetric efficiency) is a constant for a given cylinder swept volume. The constant is 1.184 (g/liter) × cylinder displacement (liter/intake stroke) based on air density at STP.

Characteristics of LOAD_ABS are:

- Ranges from 0 to approximately 0.95 for naturally aspirated engines, 0 – 4 for boosted engines,
- Linearly correlated with engine indicated and brake torque,
- Often used to schedule spark and EGR rates,
- Peak value of LOAD_ABS correlates with volumetric efficiency at WOT,
- Indicates the pumping efficiency of the engine for diagnostic purposes.

Spark ignition engine are required to support PID 43. Compression ignition (diesel) engines are not required to support this PID.

2.2 Identification of a common load variable for vehicle testing purposes

One of the objectives of the Pre-Study was to identify variables correlated to the engine load that could be used to monitor this parameter during emission tests performed with a vehicle on a chassis dynamometer.

As already mentioned above, the engine load is basically related to the output of the engine in terms of work per unit of time. Obviously the output of a given engine depends on the input energy (i.e. fuel) admitted per unit of time. Therefore there are two main options to monitor the load of the engine: either the output is measured (that means measuring the effective power, i.e. the engine torque × engine speed) or the input (fuel rate). There are however many other variables that are correlated to these two main variables. Some examples are given in Table 2 below.

Table 2. Identified variables related to the input and output of a thermal combustion engine of the L-category.

Fuel rate	Effective power of the engine
Air mass flow (spark ignition engines)	Engine shaft torque
Injection duration (engines with electronic fuel injection)	Torque/power at the wheel
CO_2 mass emissions	Brake Mean Effective Power
Exhaust flow rate	Indicated Mean Effective Power
Vacuum level in the intake manifold (Manifold Absolute Pressure)	
Position of the throttle	
Pressure inside the cylinder	
Heat release rate	
Calculated_Load (PID 04)	
Absolute_Load (PID 43)	

In principle, all these variables could be monitored and recorded during a test. However, from a practical point of view, not all the variables are straightforward to log and to process/interpret. In some cases there are practical issues that prevent from accurately logging some of the variables, in other cases the signal acquired is too noisy to be useful.

First of all, it is necessary to distinguish the case of an engine installed on a test bed from a vehicle tested on a chassis dynamometer.

Engine test beds are designed to properly measure the full load curve and, with the appropriate equipment, the full rpm and power range can be explored. The torque of the engine is directly measured and the engine can be easily fitted with additional sensors that allow to fully characterize the engine itself.

If the engine is instead installed on a vehicle (in this case an L-cat vehicle) there are a number of issues that can heavily limit the range of rpm and power that can be investigated. Here below a non-exhaustive list of practical issues to be taken into consideration.

2.3 Facility related issues

- Maximum speed and power of roller benches (typically roller benches have maximum speeds that are in the range of 150-200 km/h since the legislative cycles for emission testing have maximum speed at around 130 km/h).

- Speed of the cooling fan. In some cases the cooling fan in the emission test cell has a maximum speed of 50 km/h. In some other cases the cooling fan is able to follow the vehicle speed but up to a certain value (typically 130 km/h). If the air flow from the fan is not enough to ensure a proper cooling of the engine/wheels safety issues will arise (risk of explosion of a tyre, or engine/exhaust system overheating).

- Exhaust flow rate measurement. The Constant Volume Sampling (CVS) system has been developed to measure exhaust emissions without the need to measure the exhaust flow rate, which is still a difficult task from a technical point of view. In some facilities the exhaust flow rate is anyway measured either by measuring the dilution air flow rate (diluted exhaust flow rate minus dilution air flow rate is equal to the raw exhaust flow rate) or using the CO_2 tracer method (requiring the measurement of both raw and diluted exhaust CO_2 concentration). However, these methods are not always very accurate, especially at low exhaust flow rates (e.g., idling) that are typical of many L-cat vehicles.

- CO_2 mass emission. It can be measured continuously in many test facilities by using a dedicated analyzer. However, if the CO_2 emissions are measured at the tailpipe outlet or at the exhaust manifold, there is a non-constant (depending on the exhaust flow velocity) time lag between the measured value and the operating condition of the engine to which that value is referred to (time for the exhaust to go from the combustion chamber to the tailpipe exit). In addition, to convert the CO_2 concentration in mass flow rate the exhaust flow has to be known; hence the above mentioned issues with the exhaust flow come into play. Moreover, if the second-by-second exhaust flow rate and CO2 concentration values are not perfectly aligned the resulting mass emission value will be not correct.

2.4 Vehicle related issues

- L-category vehicles range from very simple technologies (two-stroke engines with carburetors) to sophisticated spark ignition engines (fuel injection electronically controlled and three-way catalyst) as well as to simple diesel engines without any electronics. This makes the selection of a load variable common to all these kind of vehicles quite demanding. A variable that can be easily measured in some vehicles has no meaning or is impossible to measure in other vehicles.

- In a standard vehicle emission laboratory of research organizations like the JRC, quite often the tested vehicles are hired from dealers or rental companies. In these cases, the amount of information available on the vehicle is quite limited. As an example, the road loads which define the resistance to progress are usually not known, and the standard values given in the legislation are used. This in general results in inaccurate fuel consumption or emission measurements compared to on-road values.

- If the vehicle is equipped with an electronic central unit (ECU), the data that can be logged depend very much on the model and on whether the data logger is properly configured. In this case, the help of the manufacturer would be necessary due to the lack of standardization.

- Specific components of a complete vehicle are quite often very difficult to reach. Sometime it is necessary to dismantle part of the motorcycle fairing to access the engine or the intake manifold. In addition, invasive operations are in some cases required to fit a sensor to the engine (e.g. MAP sensor).

- Sensors to measure different parameters (MAP, in-cylinder pressure traducers, throttle position sensors, etc.) are available on the market. However, there is no generic one-for-all fitting solution. The sensors should be carefully selected on the basis of the expected range of the variable to be measured and it is also necessary to calibrate and fine tuning the sensors for the specific application. This may require a lot of work that not always may be compatible with the test schedule of the laboratory.

- The Continuous Variable Transmission (CVT) represent a major challenge when measuring the full load curve of an engine installed on a motorcycle. Typically, the CVT is designed to limit the RPM within a range that represent the best compromise in terms of driveability, emissions and fuel consumption. As a consequence, even widely changing the resistance simulated by the roller bench (that means varying the load applied to the engine) the resulting rpm of the engine will be concentrated in a very narrow range.

Obviously, most of the above mentioned issue can be easily solved with the support of the manufacturer especially during the type approval test. In this case, type approval vehicles may be easily equipped with specific sensors so that during the test much more variables can be logged.

However, during the Pre-Study carried out at the JRC most vehicles were hired from private dealers and had to be returned at the end of the testing period, meaning that no invasive operation or permanent modifications (like drilling holes in the intake manifold or similar) were possible.

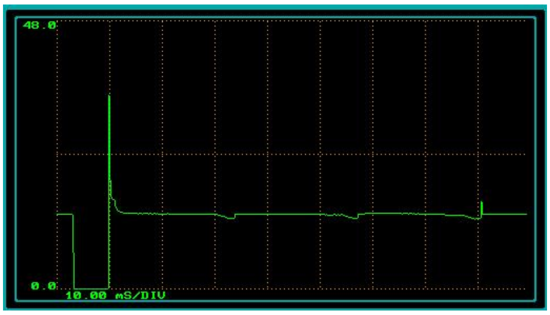
In Table 3 theoretical advantages and disadvantages of the different variables are discussed.

Table 3. Description of theoretical pros and cons of the identified engine load variables from the point of view of a vehicle emissions laboratory.

VARIABLE	**ADVANTAGES/DISDVANTAGES**
Fuel rate	The energy source for an engine is the chemical energy stored in the fuel. Fuel rate can be measured directly with instruments or indirectly through a carbon balance method (measurements of HC, CO and CO_2 emissions during the emission test). There are systems to reliably measure instantaneous flow rates of fuel being delivered to the engine (e.g. AVL KMA mobile[1]). This system (KMA) has been used in several tests carried out by the JRC. Data obtained are described in the following chapters. **Disadvantages** Most of the fuel energy goes out of the exhaust pipe as lost heat: approximately 1/3 of the fuel energy is lost to the cooling system (coolant, oil and surrounding airflow). Some of the remaining power is lost for mechanical movements of the piston, driving accessories (oil pump, coolant pump, alternator, vacuum pump, hydraulic pump, etc.), losses from pumping air through the engine, thrashing the oil in the

[1] https://www.avl.com/-/avl-kma-mobile

	crankcase, and friction in various forms. Approximately 1/3 of the energy is available for power output, but the actual efficiency of the engine is not constant over the area of operation. For an accurate estimate of the fuel rate the carbon balance should be calculated using the actual properties of the fuel (that must be known after a fuel analysis). In general, it is instead calculated using average values taken from the legislation and this introduces a systematic error. In addition, since exhaust emission are measured either in the raw or diluted exhausts, there is the uncertainty due to the delay between the measurement of the concentration of pollutants and the engine operating conditions. **Advantages** The fuel rate is correlated to the power output. The relationship is linear in a limited region of the engine map (typically at low-medium loads). The fuel rate can be quite easily measured or calculated in an emission laboratory also if the engine is installed in a complete vehicle.
Air mass flow	The energy contained in the fuel is released through the combustion process that basically consists in converting hydrocarbons in $CO2$ and $H2O$ through oxygen. Since oxygen makes up about 23% (m/m) of the air, there is a specific mass of air needed to completely burn a given mass of fuel. The air mass flow is typically measured with specific sensors (mass air flow, MAF, sensors) based on different measuring principle (e.g., hot wire). *This variable has not been investigated by JRC in the Pre-Study.* **Advantages** The air mass flow is closely correlated to the fuel rate and therefore to the power output. This is of course true for engines running in stoichiometric or very close to stoichiometric conditions (port fuel injection engines). The mass air flow is typically available from OBD systems used in passenger cars. In theory any engine could be fitted with an air mass flow sensor. **Disadvantage** The OBD of L-cat vehicles typically does not record the air mass flow yet. It is likely that during the development of the

	OBD global technical regulation at United Nations level (UNECE-EPPR)[2] this signal will be made available. Suitable mainly for spark ignition engines. For diesel engines, the flow of air is less correlated to the fuel delivered to the engine (combustion occurs in excess of air). Air mass flow sensors are very difficult to install when the engine is already installed on a vehicle for emission testing purposes. *This option has not been investigated by the JRC.*
Injection duration	When the engine is equipped with a fuel injection system, the volume of fuel injected is determined by the injection duration, i.e. the time during which the needle of the injector is lifted. The interval during which the injector is open is called pulse width. Depending on the system design, the timing of when injector opens is related to each individual cylinder (for a sequential fuel injection system). In most cases the injector has a power supply from a system relay and a switched ground wire connected to the ECU. In some cases the ECU controls the positive injector side and the negative side is permanently connected to ground. An example of a recorded injection pulse width is given in the picture below.  Figure 2. Example of pulse width. **Advantages** In principle the pulse width may be easily recorded with an oscilloscope once the wire connected to the injector has been identified: With the help of an inductive clamp the duty cycle can be displayed and logged on a portable (relatively cheap) scope.

[2] Environmental and Propulsion Performance informal working group: https://www2.unece.org/wiki/pages/viewpage.action?pageId=5800520

	The higher the duty cycle, the higher the engine torque. It is proportional to the amount of fuel delivered. **Disadvantages** Suitable only for engines with electronic fuel injection. Signal values may differ on different types of engine control units and injectors and this requires a fine tuning and calibration phase every time a new vehicle has to be tested in order to avoid problems such as a noisy signal or poor connection. The noise signal could be circumvented by putting a needle through the injector wire and to connect the probe of the scope / multi-meter directly. *This variable has not been investigated by JRC in the Pre-Study but* ***we recommend doing this acquisition during the Effect Study.***
CO_2 mass emissions	Time-resolved CO_2 mass emissions can be measured if a suitable analyzer configuration is available. The test facility must be equipped with a dedicate analyzer bench that can measure the CO_2 concentration in the raw exhaust. In addition, the exhaust flow must be known with the same time resolution. **Advantages** CO_2 mass emission per unit of time is proportional to the fuel consumption. **Disadvantages** There is a time lag between the measured value and the operating condition of the engine to which that value is referred to. Attributing the measured CO_2 concentration to the right engine operating condition is not always a trivial task when the time resolution is in the order of 1 s. Need of exhaust flow measurements to convert the CO_2 concentration in mass emissions. This option has been investigated by the JRC. Results are given in the following chapters.
Exhaust flow rate	Typically, the exhaust flow rate in an emission test facility is calculated by the difference between the diluted exhaust flow rate in the CVS and the dilution air flow rate. This can be obtained either by measuring the CO_2 concentration in the raw and diluted exhaust (CO_2 tracer method) or by directly measuring the dilution air flow. **Disadvantages** The CO_2 tracer method is not reliable in the first seconds of the test, when the air exits the exhaust but has not yet reached the analyzers installed at the dilution tunnel. This would make it impossible to assess the mass emission of pollutants during the cold start operation (cold start emissions). Also, during the fuel cut-off this method does not work.

	With small engines the exhaust flow will represent a very small fraction of the diluted exhaust. The difference between the large diluted exhaust and the large dilution air flow will be small and affected by a large uncertainty, especially during idling.
Manifold Absolute Pressure (MAP)	Manifold absolute pressure sensors (MAP sensor) are typically used in internal combustion engines' electronic control system. Engines that use a MAP sensor are typically fuel injected. The MAP sensor provides instantaneous manifold pressure information to the engine's ECU. The data is used to calculate air density and determine the engine's air mass flow rate, which in turn determines the required fuel metering for optimum combustion. MAPs represent an alternative option to MAF sensors described above. On two vehicles the MAP sensor was installed and tests carried out during the Pre-Study. In general, recent high performance motorcycles are equipped with a speed density engine management system. The MAP sensor is already installed and should give good correlations with the engine load (at least for those without ETC). In addition, it is expected that when the emission requirements become more severe, the throttle position sensor will be supplemented by the MAP sensor for the calculated engine load. **Disadvantages** ECUs on L-category vehicles do not usually record or make available MAP values. Installation problems on a complete vehicle: First of all, an invasive operation may be required (e.g. drilling a hole in the intake manifold). In addition, it is difficult to establish where the MAP sensor should be placed for an optimal reading of the pressure in the manifold. Output: For small motorcycles and mopeds the range of MAP values may be quite limited and may not catch different operation regimes of the vehicle in terms of load.
Throttle position	In principle, the throttle position is correlated to the rate of the fuel delivered to the engine and therefore to the load. If not available from ECU signals, it is quite easy to measure and record the handle/pedal position with a simple potentiometer. **Advantages** The throttle position is usually well correlated to the fuel delivered and can be measured with inexpensive sensors. **Disadvantages** In some cases there is no physical link between the handle/pedal and the throttle (drive by wire) or there is a

	leverage defining a specific acceleration law. This means that there is no linear relationship between the handle/pedal and the throttle position. In addition, in conventional spark ignition engines the throttle position usually determines the amount of air aspirated by the engine. In carburetted engines the depression created in the venturi nozzle determines the amount of fuel entering the cylinders. In fuel injected engines, the ECU provides the correct amount of fuel to be delivered on the basis of the mass air flow measured by means of suitable sensors (MAF or MAP). However there also engines adopting a reverse strategy: Each position of the pedal/handle corresponds in the ECU to a specific power output and consequently to a fuel rate. The amount of air is determined consequently. Usually not available from ECUs of the smallest L-category vehicles (e.g., mopeds).
Combustion chamber pressure	The pressure inside the combustion chamber, which is correlated to the amount of fuel burned, can be measured by means of specific pressure transducers. **Advantages** Variable directly linked to the load. **Disadvantages** In complete vehicles the possibility to install such transducers is limited by the effort required. Special spark plugs with a pressure sensor are also available on the market, but in any case vehicle specific optimization would be required (e.g., the spark plug model changes from engine to engine). Diesel vehicles would require different sensors. *This option has not been investigated by the JRC*
Heat release rate	See combustion chamber pressure
Calculated_Load (PID 04) **Absolute_Load (PID 43)**	These are variables that are typically available from the OBD system in passenger cars. It is in general quite easy to log these values from the OBD port. *The reliability of the data available from the OBD system has not been checked by the JRC.*
Effective power of the engine	The effective power of the engine can be calculated knowing the torque and the speed of the engine. The rpm value is in general available from almost all the L-cat vehicles and in any case is quite simple to be measured.
Engine shaft torque	The engine shaft torque is in general a parameter that is not available from the ECUs of L-cat vehicles. The shaft torque could be measured by means of a specific sensor but installing it would require an invasive intervention on the

	vehicle. This is something that is in general not feasible on hired vehicles. *This option has not been investigated by the JRC.*
Torque/power at the wheel	The torque/power at the wheel can be easily measured when the vehicle is tested on a roller bench. The data provided by the roller bench (that can be recorded at a frequency > 1 Hz) allows to accurately calculate the instantaneous torque at the wheel and consequently the power. The torque at the wheel is in general very well correlated to the engine load and it is used among others to optimize the engine performances on engine benches.
Brake Mean Effective Power (BMEP) **Indicated Mean Effective Power (IMEP)**	These are variables that can be calculated knowing the indicated work or the brake work as shown above. However, if it is quite easy to measure these works on an engine installed on a test bed, it is much more difficult to do that in the case of a vehicle for the reasons already explained (no possibility in general to measure the shaft torque without invasive operations). *This option has not been investigated by the JRC.*

3. Experiments and method

3.1 Test facility

The Pre-Study was conducted in the Vehicle Emissions Laboratory (VELA) of the Sustainable Transport Unit (STU), Institute of Energy and Transport (IET), Joint Research Centre (JRC) Ispra, Italy. The laboratory is able to perform emission test in accordance with Directive 70/220/EEC [5] and its following amendments, Reg.168/2013 [1] and Reg.134 [2].

The laboratory comprises:

- A chassis dynamometer: single roller of 1.22 m (48") diameter, inertia from 150 to 3500 kg, and max speed of 200 km/h (AVL Zoellner GmbH, Germany);
- A climatic test cell: temperature range from -7°C to 20°C;
- A CVS (constant volume sampler) system: insulated tunnel with a critical flow venturi from 1.5 to 11.25 m^3/min and a particulate sampling system (PTS) at 50 lpm with filters for particulates (CGM electronics, Italy);
- Two benches of analyzers for gaseous pollutants (AMA I60, AVL). The two benches allow both the measurement of concentrations in the bags and the second-by-second measurement of concentrations in raw exhaust.
- A signal acquisition system to record the output of several sensors among which a series of thermocouples used to monitor the temperature of pre and post-catalyst exhaust, engine oil/cooling water.

Several parameters were recorded during the tests (see Section 3.4): ECU parameters (engine speed, throttle position, and lambda value), manifold pressure, accelerator (handle) position, torque and power at the wheel, instantaneous fuel consumption.

A full description of the experimental system is illustrated in Figure 3.

Finally, the STU is certified ISO9001. Consequently, in addition to the routine calibration procedures, several metrological controls are constantly implemented in the VELAs across actions and procedures aiming at improving measurement quality. The objectives of these actions is to ensure metrological traceability (to national and international standards), precision (through regular use of internal quality control), and the reproducibility (through the participation to inter-laboratory comparisons) of the tests carried out.

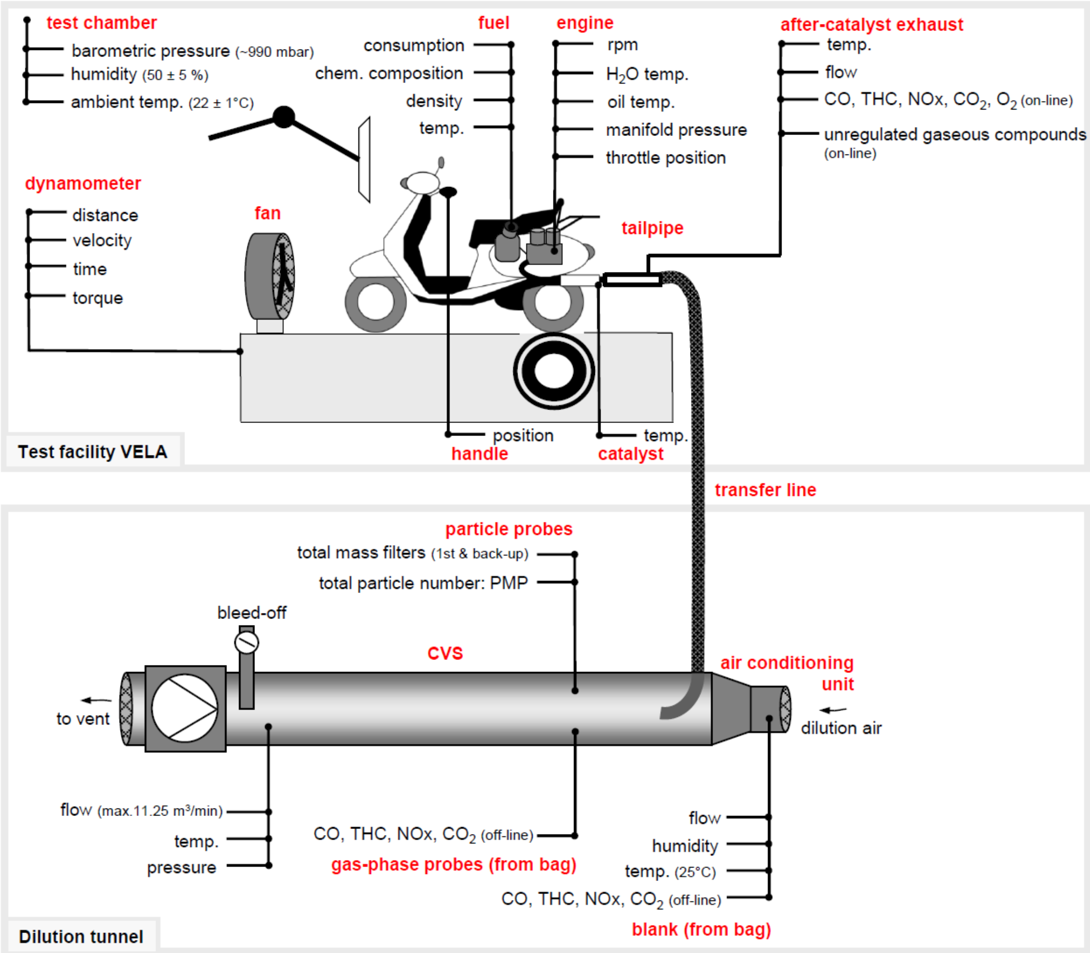


Figure 3. Schematic of the test facility.

3.2 Test fleet

A fleet composed of 12 vehicles was tested in the VELA facility. The main technical characteristics of the vehicles and the driving cycles performed are displayed in Table 4.

Table 4. Vehicle basic data sheet. Engine Power: The rated power and the measured one are reported. Technology: 2wc = 2-way catalyst (oxidation catalyst); Ca = carburetor; Inj = fuel injection; SAS = secondary air system. Maximum Speed: the vehicles maximum speed was retrieved from WOT tests and used to classify the vehicles. This data are necessary to choose the correct vehicle class and associated WMTC cycle (Reg.134). The engine capacity is rounded.

Vehicle new	Category	Category name	Engine Capacity [cc]	Power [kW]	Stroke	Max Speed [km/h]	Transmission	Technology	Euro standard	Cycles
Veh1	L1e-B	High speed moped	50	1.8	4S	45	CVT	2wc , Ca	Euro 2	R47, WMTC 1, WOT
Veh2	L1e-B	High speed moped	50	2.2 2.4	2S	45	CVT	2wc , Ca, SAS	Euro 2	R47, WMTC 1, WOT
Veh3	L1e-B	High speed moped	50	3-5	2S	45	m/t	2wc , Ca	Euro 2	R47, WMTC 1, WOT, SRC
Veh4	L1e-B	Low speed moped	50	1.2	4S	25	CVT	2wc , Ca	Euro 2	R47, WMTC 1, WOT
Veh5	L1e-B	Low speed moped	50	3 1.3	4S	25	CVT	2wc, Ca	Euro 2	R47, WMTC 1, WOT,
Veh6	L3e-A1	Low performance motorcycle	125	7.9 5.5	4S	95	CVT	2wc , Inj	Euro 3	R40, WMTC 1, WOT, SRC
Veh7	L3e-A2	Medium performance motorcycle	300	16.5 12	4S	115	CVT	2wc , Inj, SAS	Euro 3	R40, WMTC 2-1, WOT, SRC
Veh8	L3e-A2	Medium performance motorcycle	400	24 18	4S	> 150	CVT	2wc , Ca	Euro 3	R40, WMTC 3-2, WOT, SRC
Veh9	L3e-A3	High performance motorcycle	900	100 80	4S	> 150	m/t	2wc , Inj	Euro 2	R40, WMTC 3-2, WOT
Veh10	L3e-A3	High performance motorcycle	700	52 46	4S	> 150	m/t	2wc	Euro 3	R40, WMTC 3-2, WOT, SRC
Veh11	L5e-B	Light commercial Trycicle	400	7.8 4.9	D-4S	55	m/t	2wc	Euro 2	R47, WMTC 1, WOT
Veh12	L7e-A1	Heavy on-road quad	500	14.4 20	4S	90	CVT	2wc , Inj	Euro 2	R40, WMTC 2-1, WOT

3.3 Driving cycles

3.3.1 Driving cycle for type I tests

The vehicles were tested on a chassis dynamometer following the different driving cycles currently applicable in EU for type I type approval. As described in Directive 2002/51/EC [6], ECE R47 test cycle is used for type approval (Euro 2 and Euro 3) of mopeds vehicles (i.e. L1e-A and L1e-B categories). This cycle lasts 896 s and is composed of a succession of 8 elementary cycles split into a first cold phase, and a second warm phase of equal length. A similar cycle, but truncated at 25km/h, was applied for L1e vehicles designed with a maximum speed of 25km/h. ECE R47 test cycle is depicted in Figure 4.

According Directive 2002/51/EC [6], type approval (Euro 2 and Euro 3) of motorcycle (i.e. L3e) is carried out following ECE R40-based test cycle [3]. Part 1 of this cycle lasts 1170 s and is composed of a succession of six ECE R40 elementary cycles. Part 2 of this cycle lasts 400 s and is composed of an Extra-Urban Driving Cycle (EUDC). Motorcycles with engine displacement below 150 cm^3 were tested on Part 1 solely while motorcycles with engine displacement beyond 150 cm^3 were tested on Part 1 followed by Part 2 of ECE R40-based test cycle (see Figure 5).

In addition, L-category vehicles were tested according the WMTC stage 3 test cycle specified in Regulation EU 134/2014 [2]. Full WMTC cycle lasts 1800 s and is composed of 3 parts of 600 s. Each part of the WMTC Stage 3 includes an alternative reduced speed variant; Part 1 which includes 2 variants (reduced speed and 25 km/h max speed). The different combinations of WMTC stage 3 test cycle are depicted in Figure 6.

For emission testing, each phase was sampled in separate bags. Regulated emissions were estimated following Directive 70/220/EEC [5] and its following amendments. Regulated emission factors were used to assess the repeatability of the tests. However, regarding engine load variable monitoring, signals were recorded during the entire prescribed cycle.

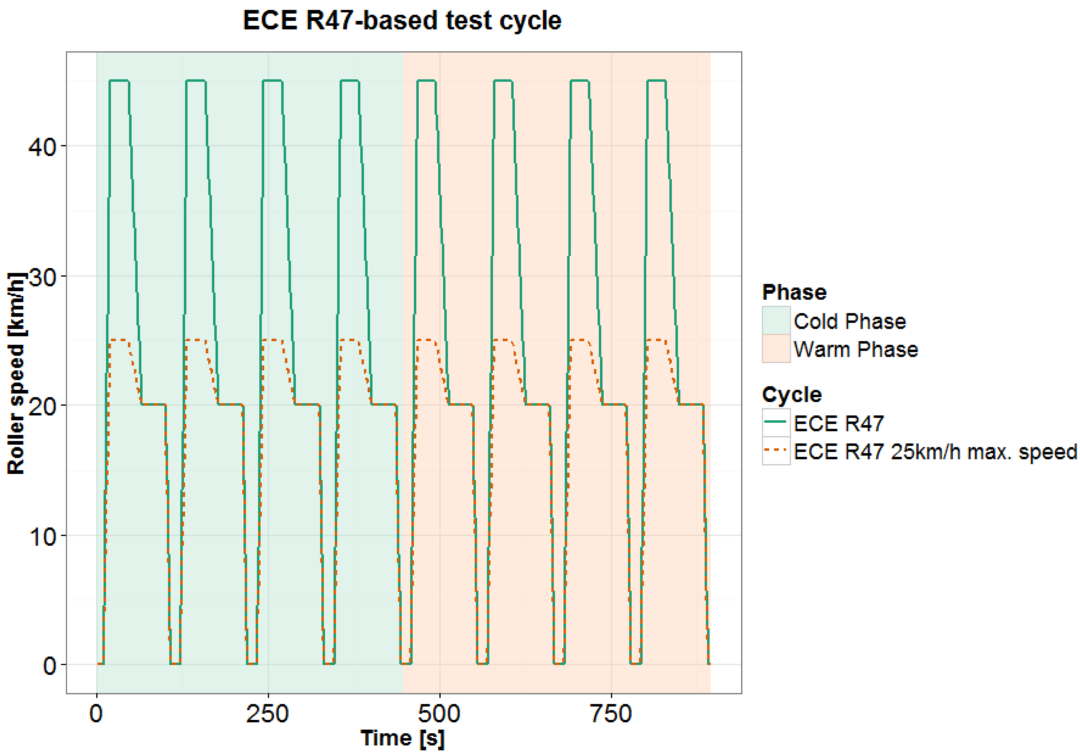


Figure 4. ECE R47-based test cycle for mopeds vehicles.

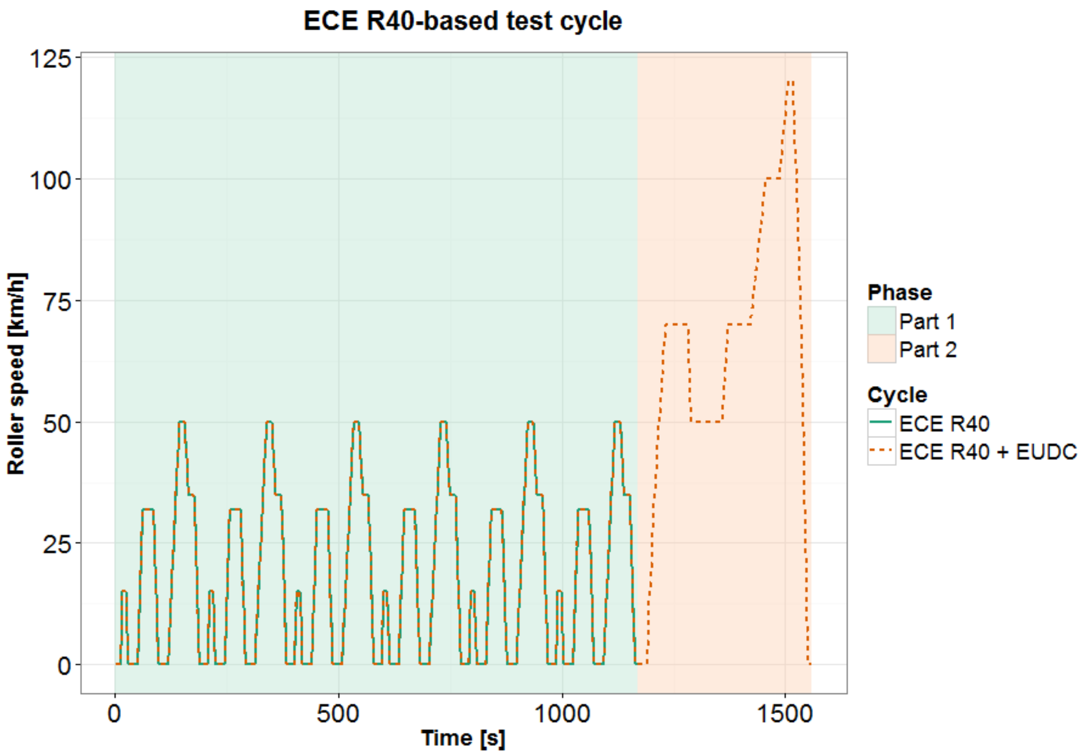


Figure 5. ECE R40-based test cycle for motorcycle vehicles.

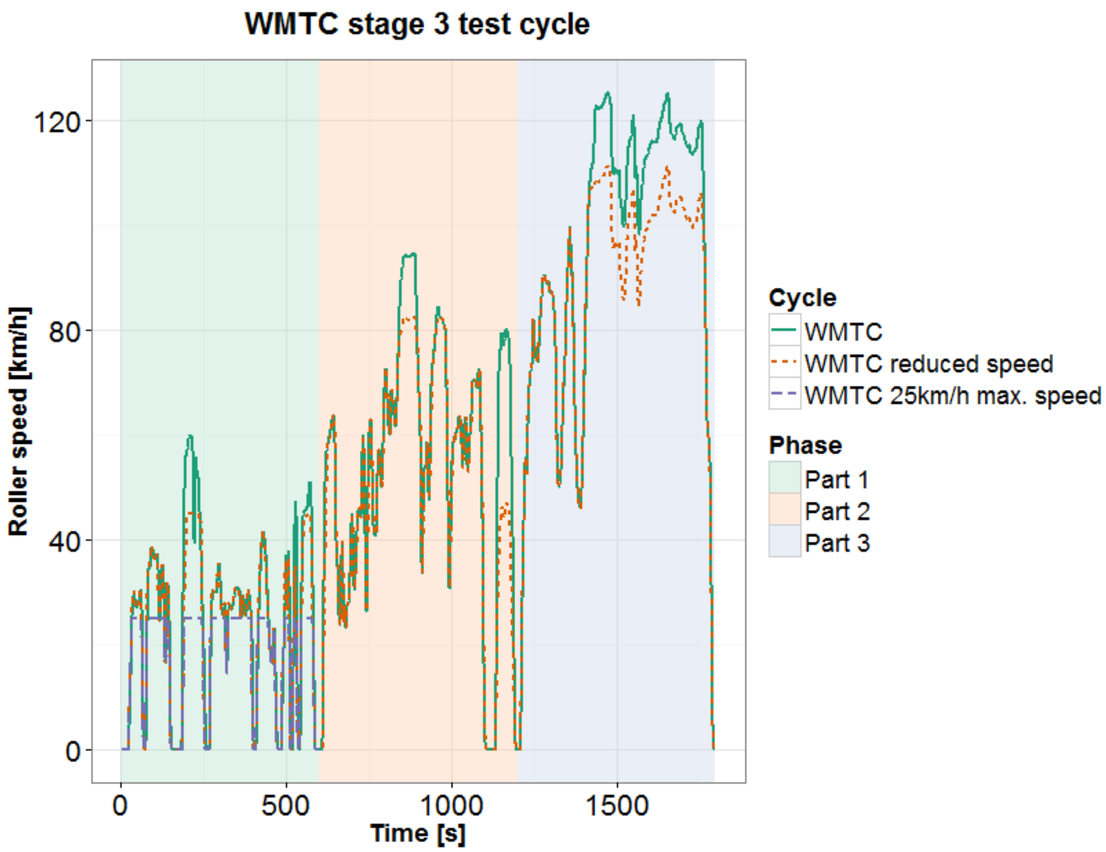


Figure 6. WMTC Stage 3 test cycle.

L-category vehicles are classified in 5 sub-classes based on their engine capacity and maximum speed, see Figure 7. Each sub-class has a dedicated test cycle composed of selected parts of the WMTC based test cycle previously presented. WMTC composition for each class and sub-class is:

- Class 1: Part 1 "reduced speed" repeated twice,
- Sub-class 2-1: Part 1 "reduced speed" followed by Part 2 "reduced speed",
- Sub-class 2-2: Part 1 followed by Part 2,
- Sub-class 3-1: Part 1, followed by Part 2, followed by Part 3 "reduced speed",
- Sub-class 3-2: Part 1, followed by Part 2, followed by Part 3.

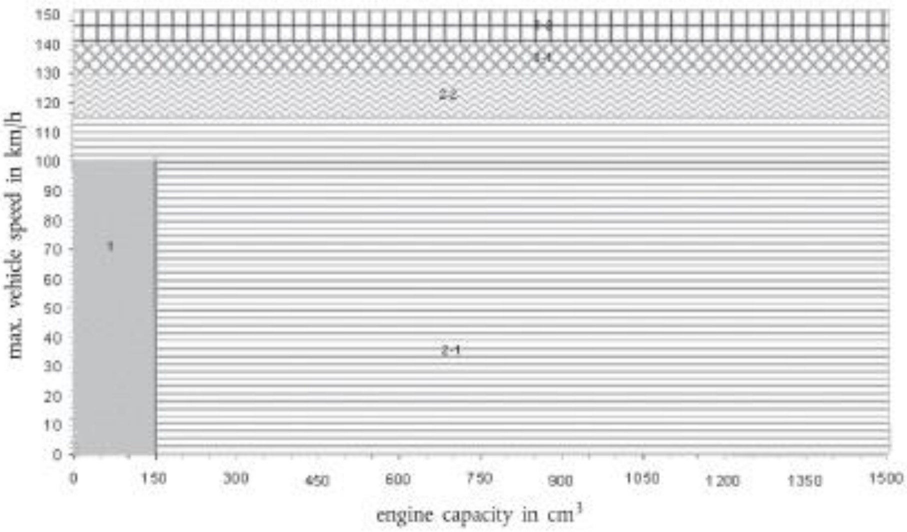


Figure 7. L-category vehicle sub-classification for test type I (Figure 1-1 in Reg. No 134/2014 [2]).

In order to compare these cycles, several basic kinetic parameters were computed. A summary of these main parameters can be found in Table 5.

Table 5. Kinetic parameters of the different driving cycles applied.

Driving cycles	ECE R47 – max. 25 km/h	ECE R47	ECE R40	ECE R40 + EUDC	WMTC P1 max. 25 km/h x 2	WMTC P1 reduced speed x 2	WMTC P1 reduced speed + P2 reduced speed	WMTC P1 +P2	WMTC P1 +P2 + P3 reduced speed	WMTC P1 +P2 + P3
Total distance [m]	4 433	6 259	5 971	12 885	5 878	7 598	12 287	13 177	27 612	28 913
Total time [s]	896	896	1 170	1 571	1 200	1 200	1 200	1 200	1 801	1 801
Drive time [s]	776	776	792	1 152	966	966	1 041	1 046	1 630	1 630
Idle time [s]	120	120	378	419	234	234	159	156	171	171
Average driving speed [km/h]	17.8	25.1	18.4	29.5	17.6	22.8	36.9	39.5	55.2	57.8
Maximum speed [km/h]	25.0	45.0*	50.0	120.0	25.0	45.1	82.5	94.9	111.3	125.3
Speed [25^{th} – 75^{th}] percentile [km/h]	[19.4-24.6]	[20.0-42.8]	[0.0-32.0]	[0.0-50.0]	[7.8-25.0]	[7.8-34.2]	[21.9-55.0]	[23.5-59.5]	[28.3-86.5]	[28.3-87.4]
Average positive acceleration [m/s^2]	0.69	1.25*	0.64	0.55	0.77	0.45	0.42	0.47	0.38	0.39
Positive acceleration [25^{th} – 75^{th}] percentile [m/s^2]	[0.69-0.69]	[1.26-1.26]	[0.53-0.74]	[0.47-0.74]	[0.39-1.14]	[0.08-0.72]	[0.11-0.66]	[0.11-0.61]	[0.06-0.53]	[0.08-0.53]

* *According Reg. 134/2014 [2] – Appendix 6, Acceleration and the higher constant speed must be executed full throttle.*

3.3.2 Wide Open Throttle (WOT) cycles

Laboratory based emission test cycles are based on vehicle speed (speed profiles). Vehicle speed, however, weakly correlates with engine load. Pre-Study aims at identifying commonly applicable engine load variables which will allow comparison of engine operation among test cycles and with real-driving. This task was achieved using dedicated driving cycles designed to explore the full operational range of L-category vehicles. Wide Open Throttle (WOT) cycles were used to explore a broader range of the engine maps. These cycles consisted in a succession of ascending steady-state velocities up to the maximum vehicle speed achievable on the roller bench, followed by a return to idle, and a full open throttle up to the previous maximum speed. The velocity was imposed by the chassis dynamometer, while the vehicle was driven full throttle. Three WOT cycles were applied to the different range of operation of L-category vehicles (Figure 8).

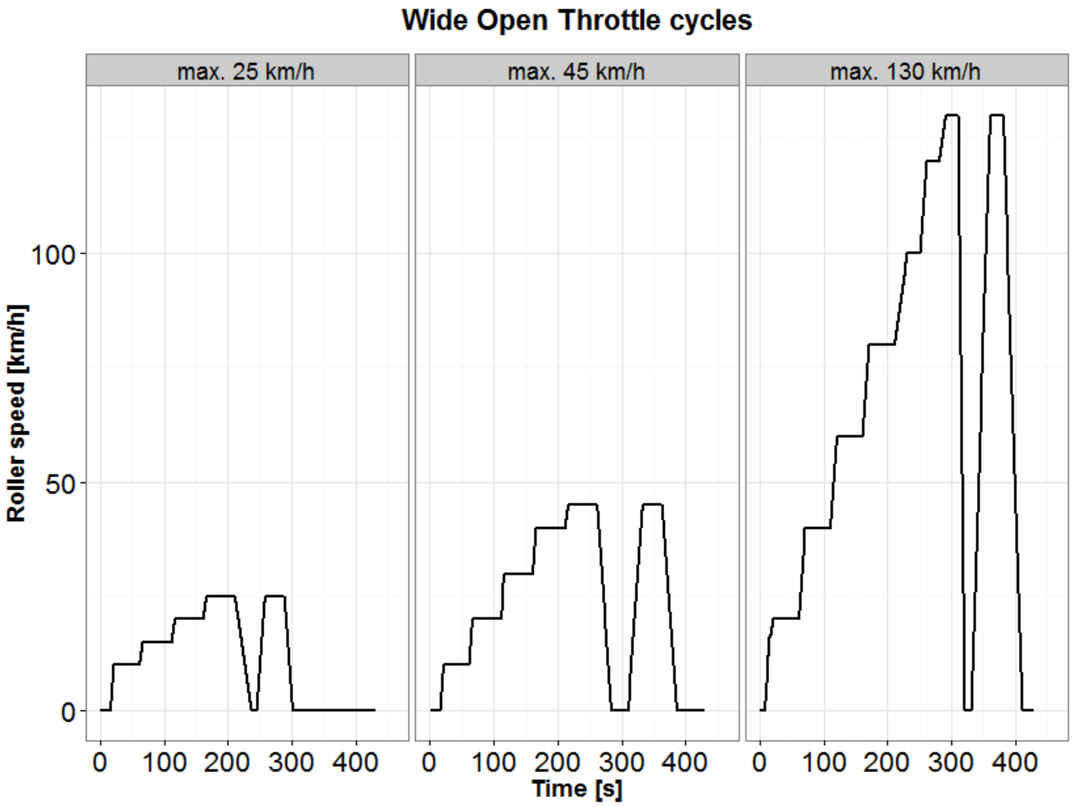


Figure 8. Wide Open Throttle cycles designed for 3 operational ranges of L-category vehicles

3.3.3 Standard Road Cycles

Durability of pollution–control devices is a requirement of Reg. 168. In accordance with Article 23(3), the Standard Road Cycle for L-Category Vehicles (SRC-LeCV) proposed for test type V was investigated in the Pre-Study. Engine load variables were monitored using this mileage accumulation cycle of which the purpose is to age pollution-control device of L-category vehicles. Based on the vehicle maximum design speed, engine capacity, and net power, 4 accumulation cycles of 30 km each are defined. Figure 9 displays the characteristics of these 4 cycles whose patterns differ for each sub-classification of L-category vehicles. In order to reach an equivalent total distance, the SRC-LeCV cycles were repeated twice. Three SRC-LeCV-based cycles were carried out during the Pre-Study. These cycles are presented in Figure 9. At the choice of the manufacturer, the cycle applied for type V mileage accumulation can be the USA EPA Approved Mileage Accumulation (AMA) cycle, see Figure 10. This cycle is composed of 11 sub-cycles covering six kilometers each, for a total driving distance of 66 km

Table 6. L-vehicle category groups for the SRC-LeCV (Table Ap1-1 in Reg. No 134/2014 [2]).

Cycle	WMTC Class	Vehicle maximum design speed	Vehicle engine capacity (PI)	Net power
1	1	$v_{max} \leq 50$ km/h	$V_d \leq 50$ cm^3	≤ 6kW
2		50 km/h < v_{max} < 100 km/h	50 cm^3 < V_d < 150 cm^3	< 14 kW
3	2	100 km/h ≤ v_{max} < 130 km/h	$V_d \geq 150$ cm^3	≥ 14 kW
4	3	130 km/h ≤ v_{max}	-	-

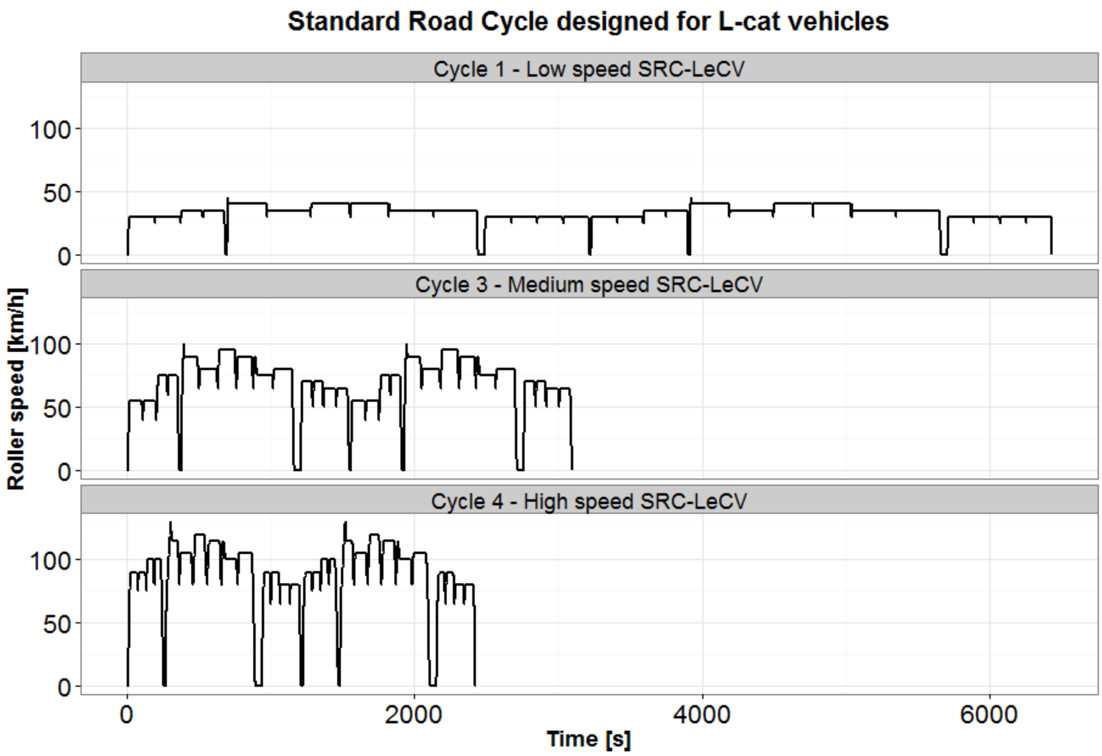


Figure 9. SRC-LeCV-based accumulation cycles.

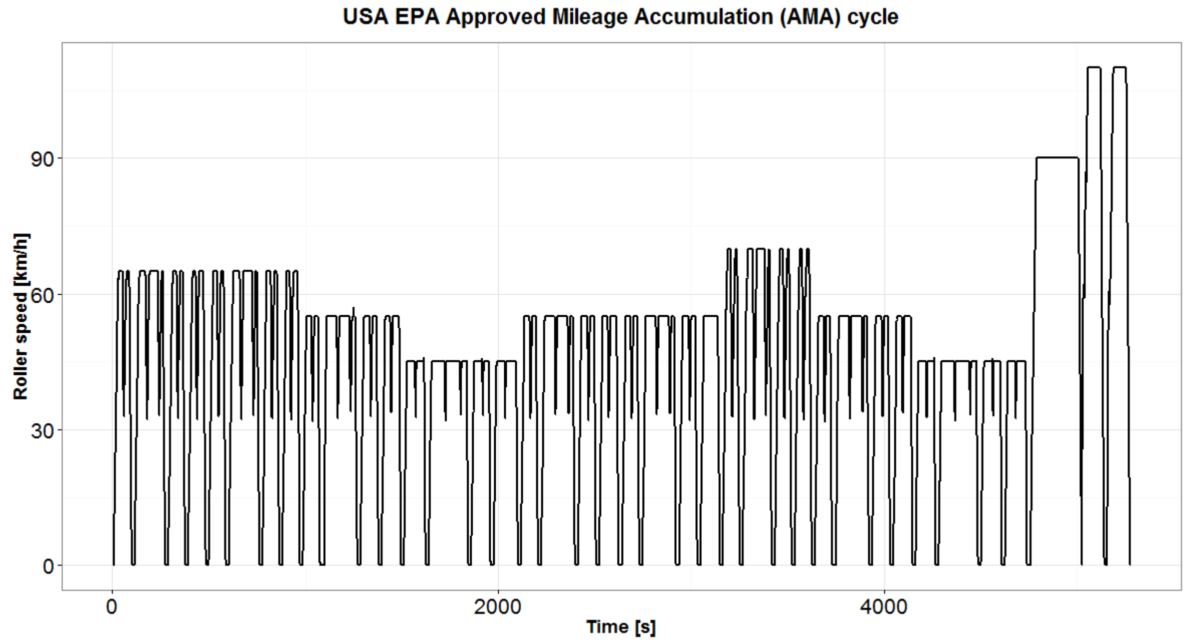


Figure 10. USA EPA Approved Mileage Accumulation (AMA) cycle.

3.4 Data description

Vehicles listed in Table 4 were tested using the driving cycles described previously. In total, more than 130 chassis dynamometer tests were performed for different combination of vehicles and test cycles.

3.4.1 Repeatability

At least 3 repetitions per test type were performed. In our experience, repeatability and reproducibility of emission tests carried out in the VELA are good based on gaseous pollutant measurements: below 10% for regulated compounds (THC, CO and NOx), and below 1% for CO2 (all integrated, bag measurements, in-house data) of a light duty gasoline Euro 6 passenger car. Of course, different vehicles of the same category may have completely different behavior. Figure 11 describes an example of repeatability for the fuel consumption variable, when Veh4 was tested over R47 driving cycle.

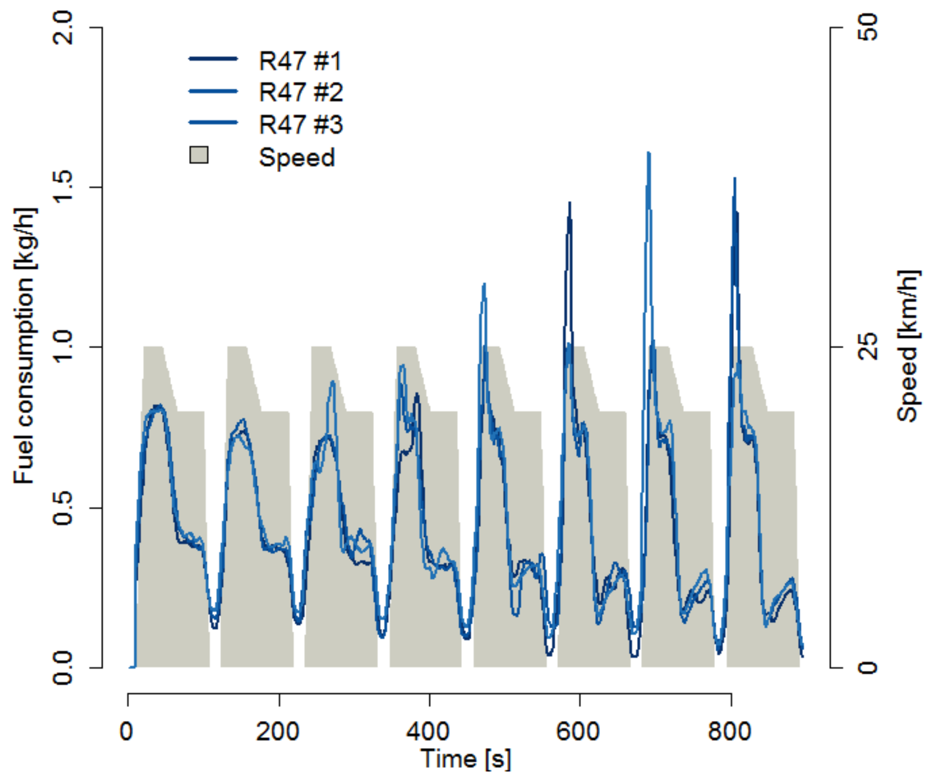


Figure 11. Example of the repeatability of signals from engine load variables. Fuel consumption registered for Veh4 over 3 repetitions of the R47 driving cycle. Vehicle speed is in light grey shaded area.

3.4.2 *Acquisition of the engine load variables*

The following variables were acquired during the tests (units in brackets):

RPM [rev/min] and Throttle position sensor [%]

Signals were acquired from the ECU with a custom made data logger with dedicated software (Eolo datalogger, Eurins).

Torque [Nm] and Power at the wheel [kW]

The dyno force measured in the load cell is obtained from coast down parameters (street F0, F1, F2), the simulated bench inertia I_sim and the roll acceleration, a, via:

Power = (F0 + F1× v + F2 × v × v + I_sim × a) × v

The Torque at the wheel can be determined as:

Torque = 9549 × Power / (Engine speed)

The Figure 12 displays an example of RPM, Power and calculated Torque signals obtained over a R40 driving cycle for Veh8.

Fuel consumption [kg/h]

The KMA system (AVL, Austria) enables the continuous measurement of instantaneous flow rates from 0.16 l/h to 300 l/h covering the range from small passenger cars to commercial vehicles up to large off-road vehicle applications with engines of up to 1000 kW. The Measuring Module is suitable for return-less engines of any type. The Conditioning Module is required for engines with a return flow to the tank. With several configurations it covers all common types and sizes of fuel delivery systems. High accuracy and resolution of the flow sensor provides very good dynamic measurement capability for transient test conditions.

Exhaust flow rate [m3/min]

The flow rate was estimated based on a conventional CVS system with a critical flow Venturi. Exhaust flow rate was calculated by difference between the total dilution tunnel flow and the dilution air flow that is directly measured using a dedicated differential pressure flowmeter. When possible, the exhaust flow rate was calculated also from the measurement of the CO_2 at the raw and diluted exhaust (CO_2 tracer method). The exhaust flow rate was corrected and expressed in the standard conditions of temperature and pressure (0°C and 1 Atm).

CO2 mass flow rate [g/s]

CO_2 volumetric concentration [ppm] is measured with NDIR (AMAi60, AVL). The exhaust flow rate is needed for converting the relative concentration in mass flow.

Figure 13 displays an example of fuel consumption, Exhaust flow rate and CO_2 mass flow rate signals over a R40 driving cycle for Veh7.

Handle position [%]

It was recorded thanks to a draw-wire displacement sensor (WDS-150-P115-SR-U, Micro-Epsilon). This instrument consists of a potentiometer linked by a wire to the handle to register the wind/rewind position of the wire (see Figure 14).

Manifold Absolute Pressure (MAP) [kPa]

It was measured with a pressure transducer positioned inside the manifold by drilling a hole in the manifold walls. Figure 15 displays an example of Manifold Absolute Pressure signal over a R47 driving cycle for Veh1.

The variables acquired for each vehicle are summarized in Table 7. The Figures below are examples of time based profiles for the engine load variables investigated in the Pre-Study.

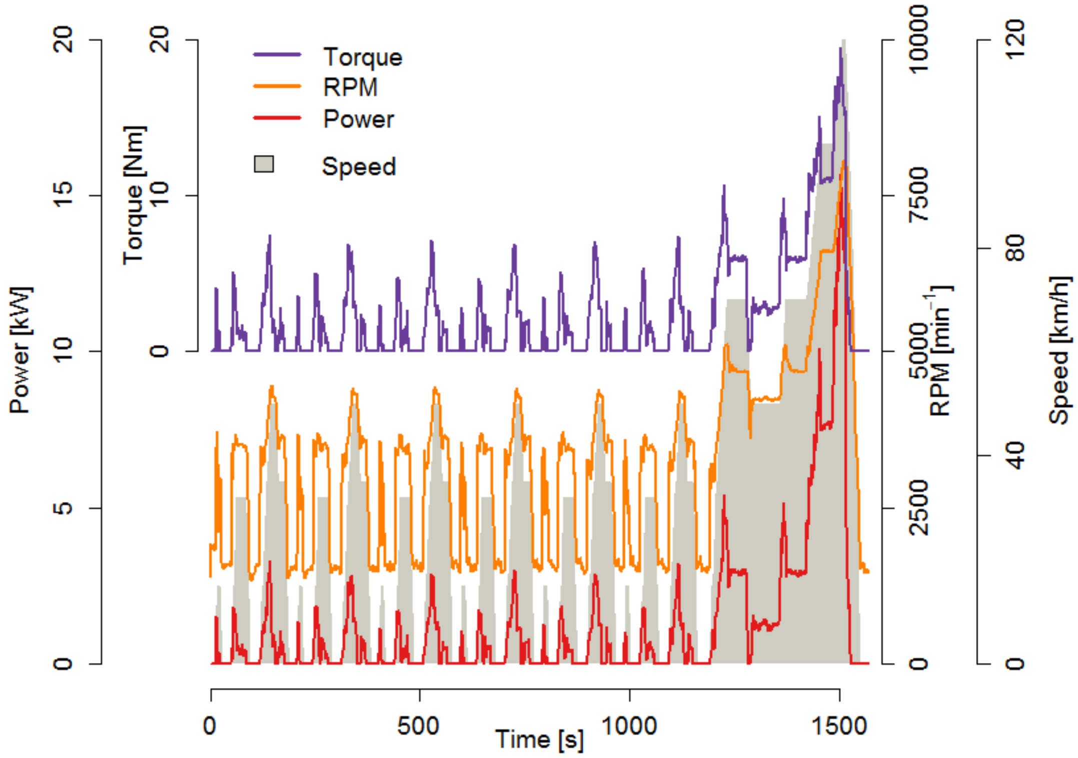


Figure 12. Veh8 over the R40 driving cycle: Power at the wheel and engine speed are plotted. Calculated torque is displayed in the upper part. Vehicle speed is the light grey area.

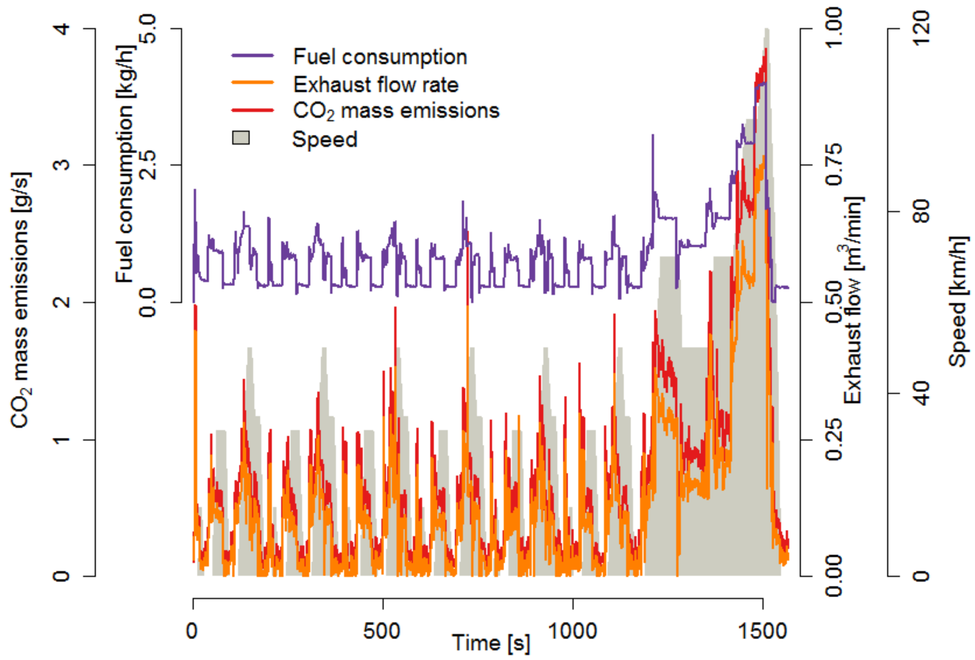


Figure 13. Veh7 over the R40 driving cycle: Exhaust flow rate and CO_2 tailpipe mass emission are plotted. Fuel consumption measured with KMA system is displayed in the upper part. Vehicle speed is the light grey area.

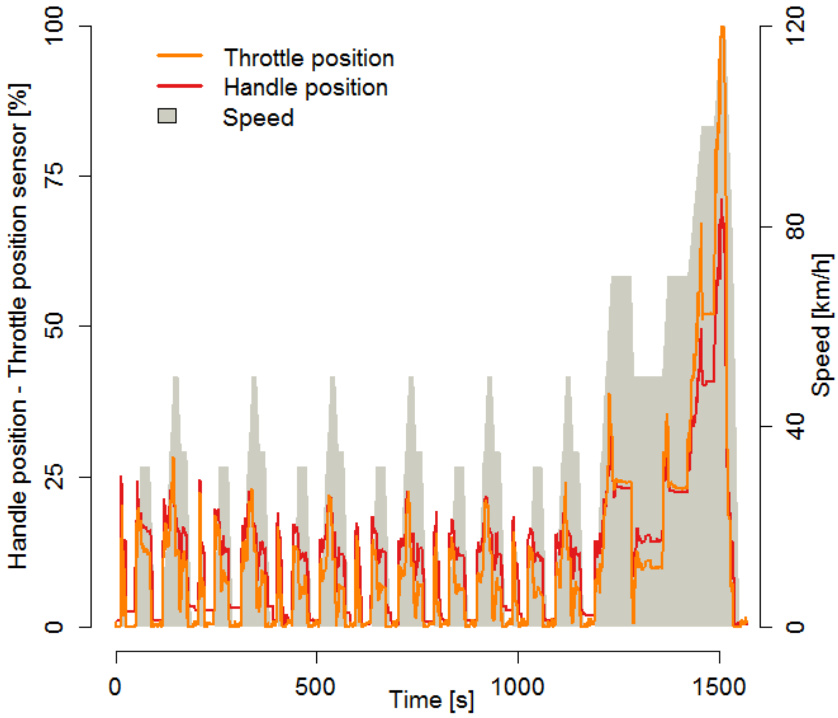


Figure 14. Veh8 over the R40 driving cycle: Handle and throttle position signals are plotted. Vehicle speed is the light grey area.

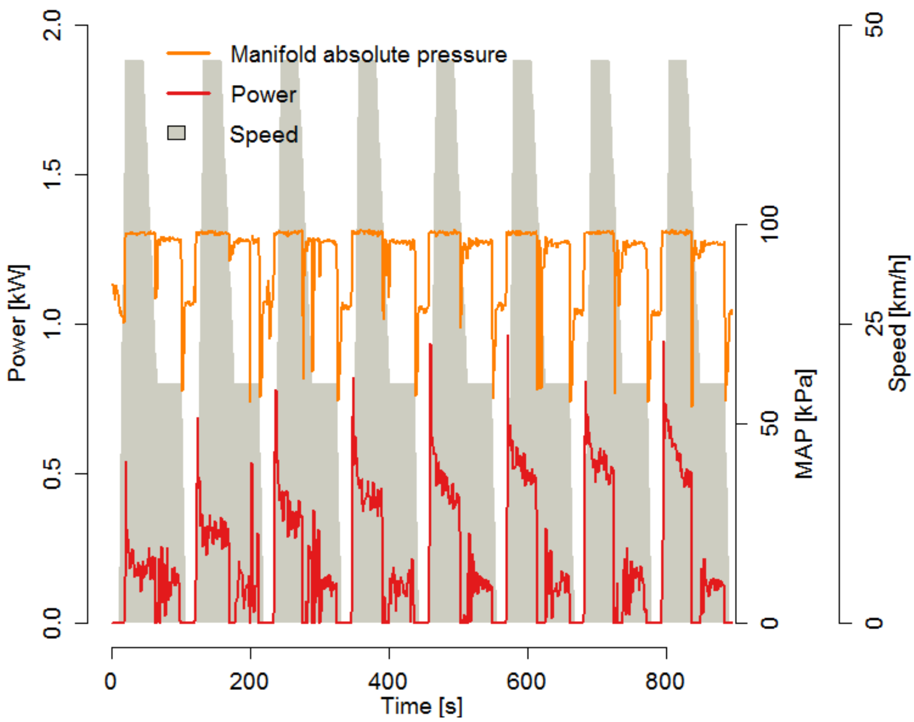


Figure 15. Veh1 over the R47 driving cycle: Power and manifold absolute pressure signals are plotted. Vehicle speed is the light grey area.

Figure 16: Handle sensor (wire potentiometer) mounted on a moped. It allows the precise determination of the position of the accelerator.

Table 7. Investigated engine load variables (green fill) per vehicle.

	Torque	**CO_2 mass**	**Fuel consumption**	**Handle position**	**Exhaust Flow**	**MAP**	**Throttle position**
Veh1							
Veh2							
Veh3							
Veh4							
Veh5							
Veh6							
Veh7							
Veh8							
Veh9							
Veh10							
Veh11							
Veh12							

3.4.3 Indicators for quality, quantity and dynamics

The assessment of the emission laboratory test cycle is based on the new basic paradigm: **clean and efficient vehicle in each and every feasible engine speed – engine load operation point under the max torque curve**.

The indicators used for this assessment are sampling quality, quantity and dynamics applied to the present driving cycle (R47 and R40) and the WMTC. The driving cycle that provides better quality, and more quantity and dynamic ranges is the favored cycle in terms of the vehicle propulsion and environmental performance assessment.

Quality

This indicator is related to:

- *Driveability*: number of violations occurred during the test cycle due to the lack of propulsion performance of the vehicle. We did not consider the violations due to the driver's ability, as our tests are not meant for type approval purposes;

- *Sampling Area*: area covered by the test/sampling points in the torque versus engine speed plots, as presented in Figure 1. The area under the maximum torque curve obtained during the wide-open throttle (WOT) test cycle represents the WOT region. As a consequence, the R40/R47 and WMTC cycles will cover a portion (indicated with a percentage) of the WOT region. The higher this portion, the better the cycle represents the entire operation range of the vehicle.

Quantity

This indicator is described by the frequency distribution (counts) of torque at the wheel compared to the engine speed. Given the longer duration of WMTC compared especially to the R47, the Quantity indicator exhibits larger counts for the WMTC. In particular, the range of values covered by the torque variable and the intensity of sampling (counts) in the high-load part of the range are of interest for this study.

Dynamics

This indicator is defined as the variations in torque at the wheel ratio the time interval of this variation during the acceleration region of the driving cycle, Δ(torque)/Δ(time).

4. Experimental Results

The test results are grouped by vehicle and are presented according to the following sequence:

- Torque and Power at the wheel against engine speed (*Quality* of sampling points);
- Torque and Power at the wheel frequency distribution (*Quantity* of sampling points: range and amount);
- Available engine load variables against engine speed;
- Best correlations between engine load variables and torque/power at the wheel.
- *Dynamics*: ratio of the torque at the wheel variation over the time of the variation during acceleration phases.

The torque and power plots describe the amount and location of the test/sampling points versus the engine speed for 3 types of driving cycles:

- Present legislative driving cycle (e.g., R40, R47), also called pre-Euro 5 cycles or statutory cycles;
- WMTC driving cycle (which is already agreed upon for sub-category L3);
- Wide Open Throttle cycle. This represents the upper limit under which the partial load operation of the engine will fall.

The guiding idea is that a driving cycle is more representative of the vehicle performance when the test/sampling points maximize the covered area under the max torque/power curve.

4.1 Vehicle 1

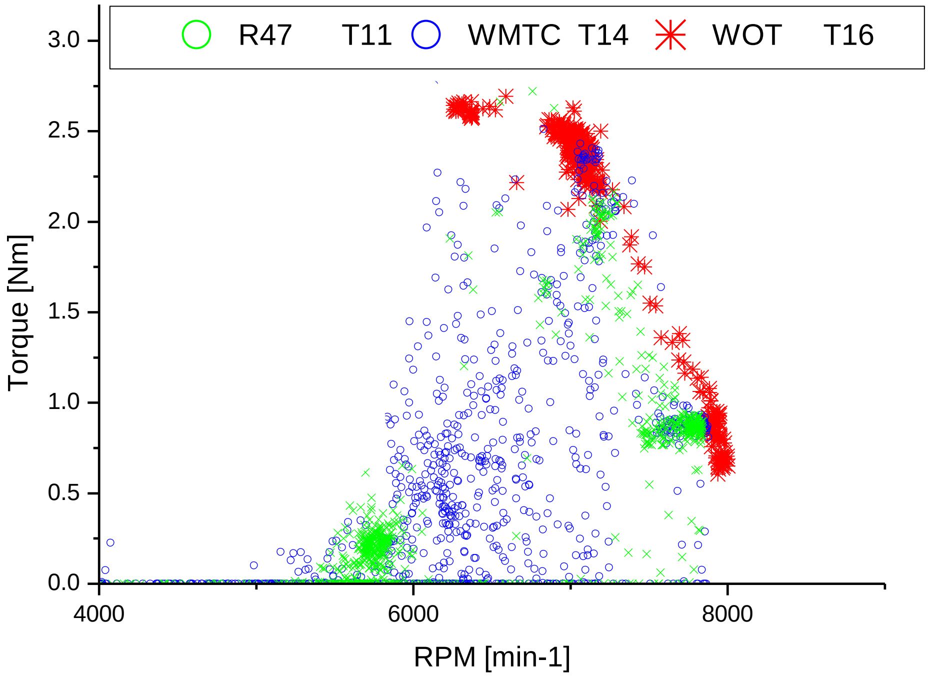


Figure 17. Vehicle 1. Torque (vertical axis) VS engine speed (RPM, min-1) for different driving cycles.

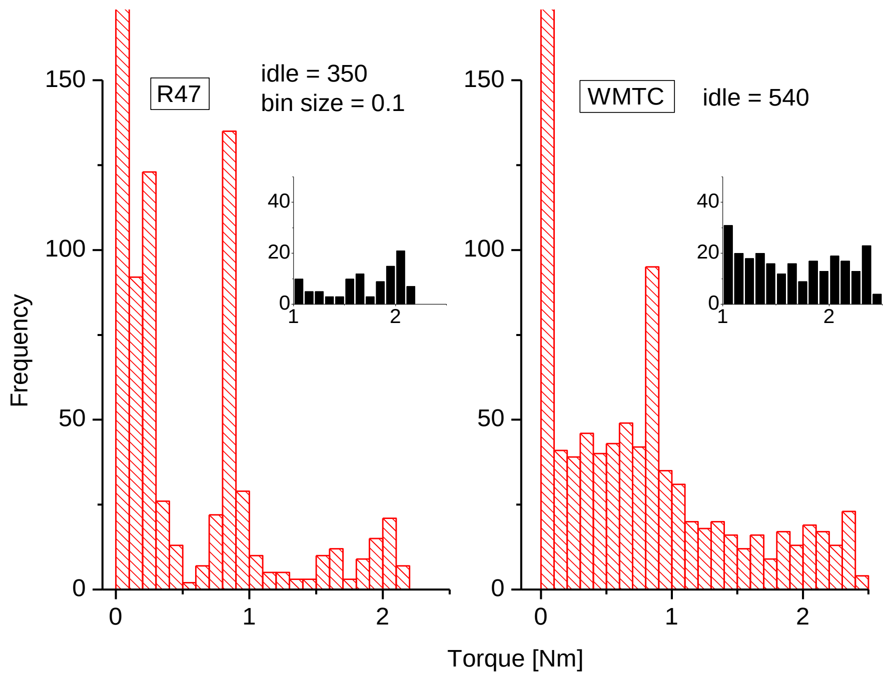


Figure 18. Vehicle 1. Distribution of counts (frequency) for the torque on the horizontal axis.

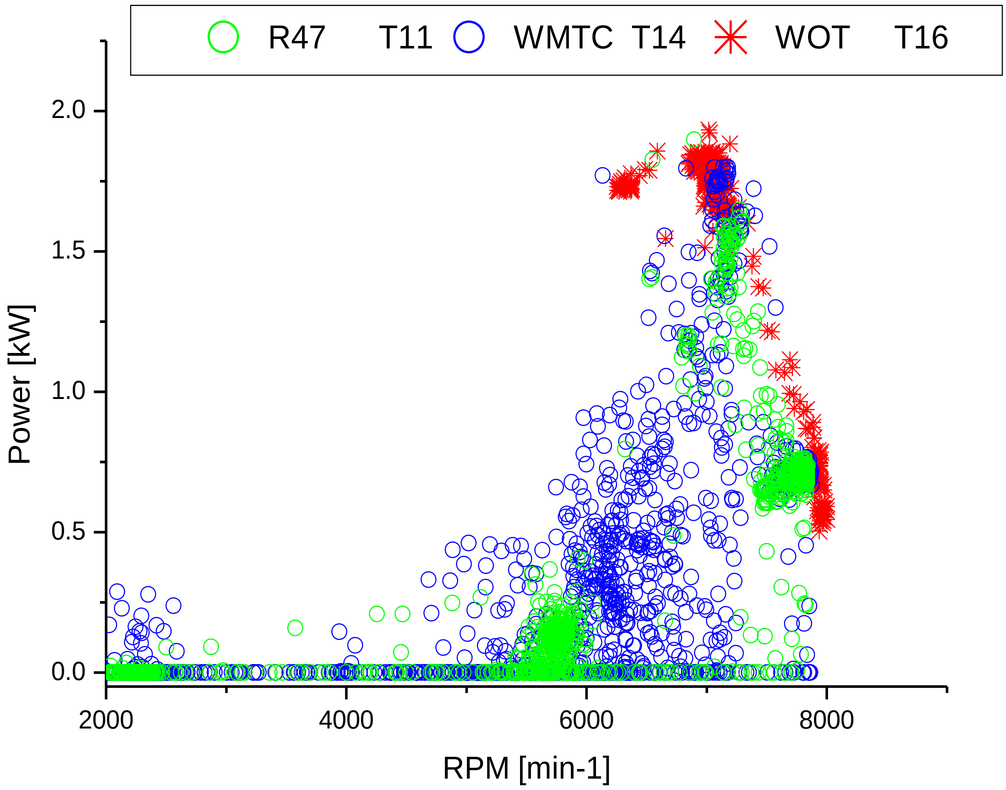


Figure 19. Vehicle 1. Power (vertical axis) VS engine speed for different driving cycles.

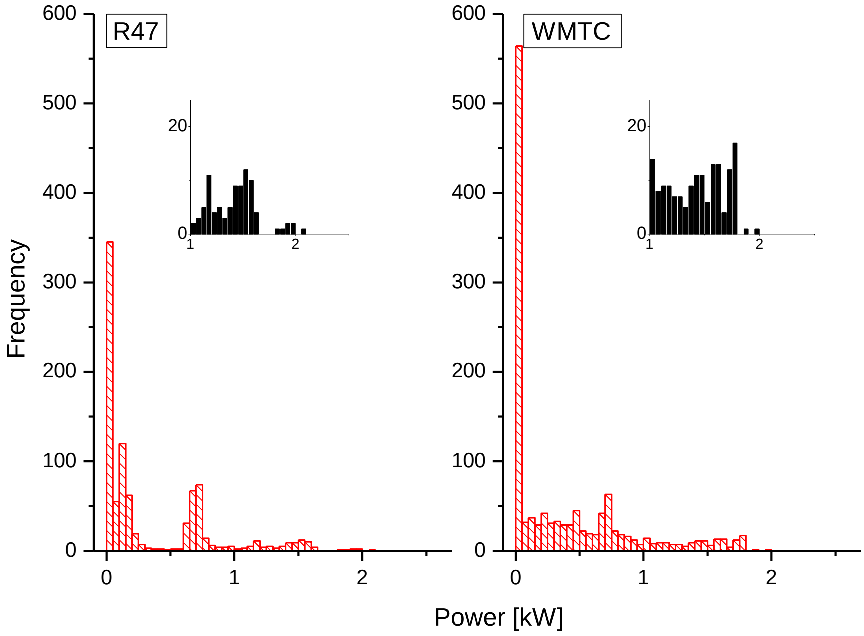


Figure 20. Vehicle 1. Distribution of counts (frequency) for the power on the horizontal axis.

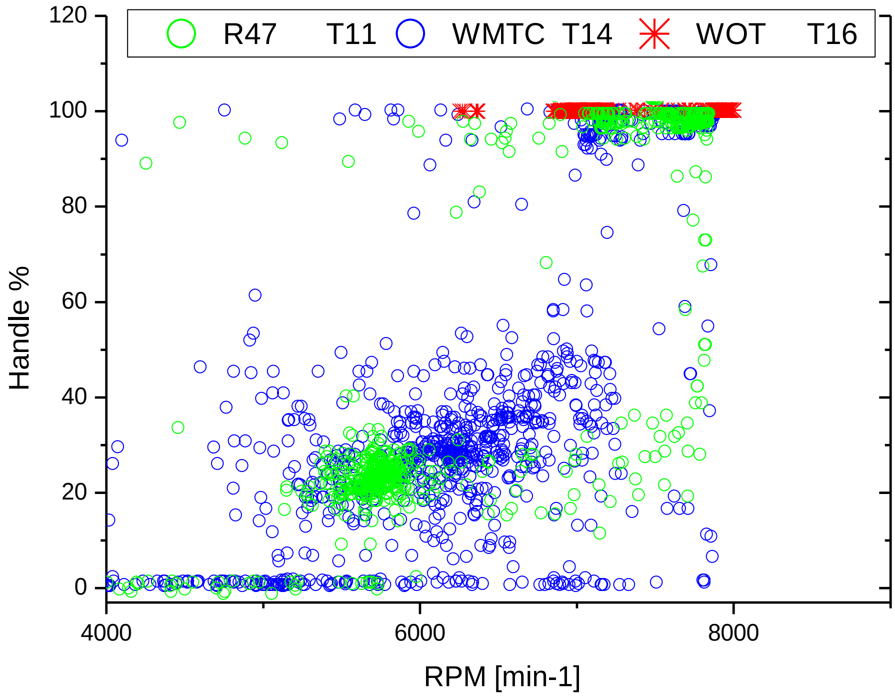


Figure 21. Vehicle 1. Handle position (vertical axis) VS engine speed for different driving cycles.

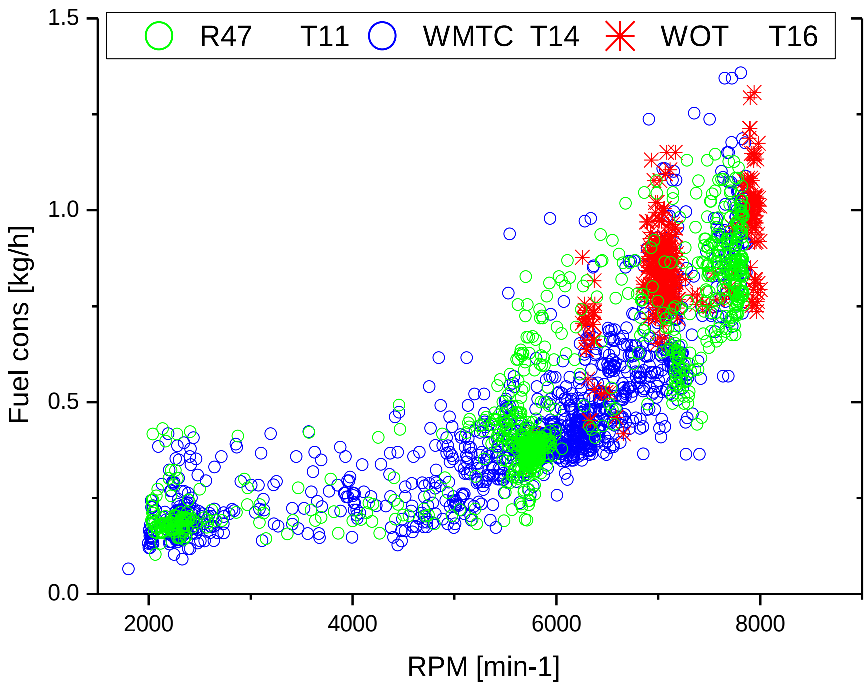


Figure 22. Vehicle 1. Fuel consumption (vertical axis) VS engine speed for different driving cycles.

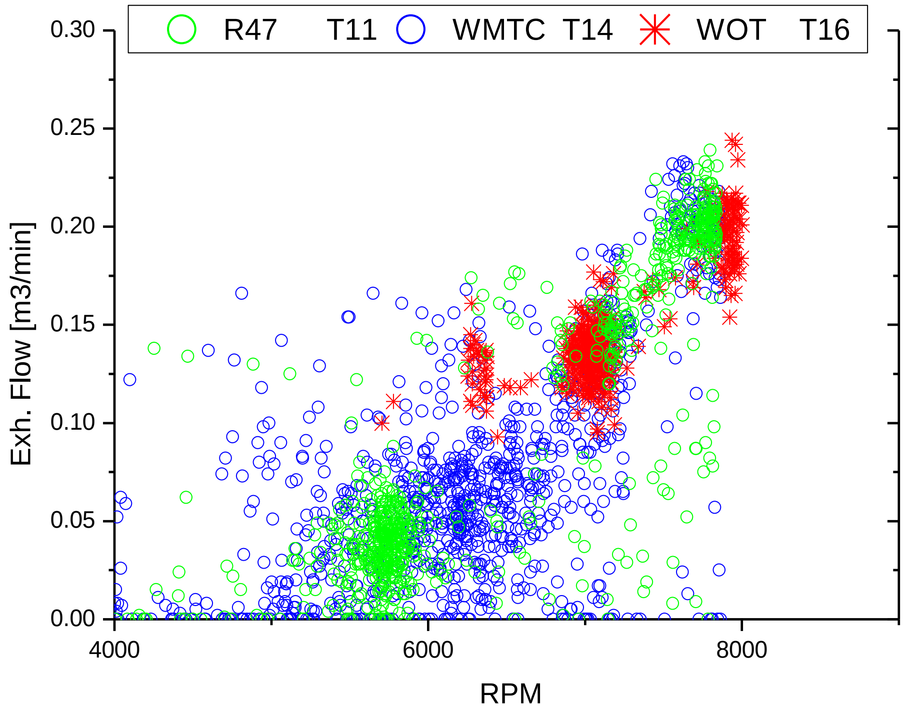


Figure 23. Vehicle 1. Exhaust flow (vertical axis) VS engine speed for different driving cycles.

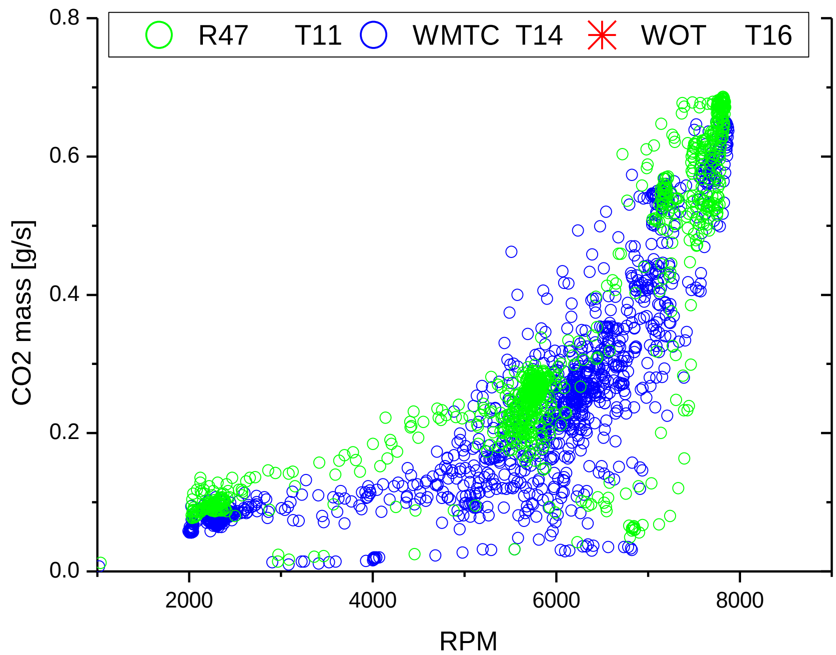


Figure 24. Vehicle 1. CO_2 mass emissions (vertical axis) VS engine speed for different driving cycles.

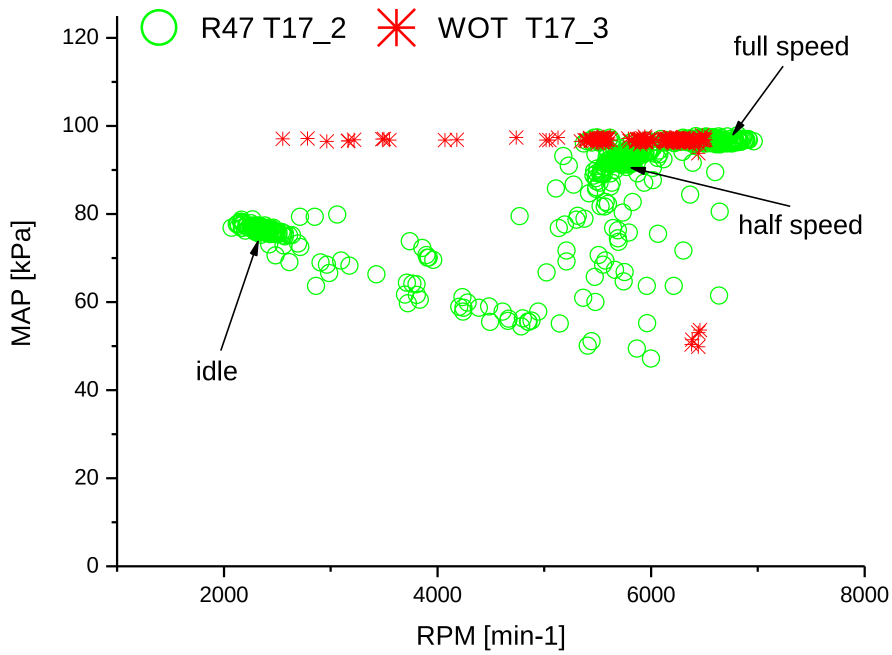


Figure 25. Vehicle 1. MAP (vertical axis) VS engine speed for different driving cycles.

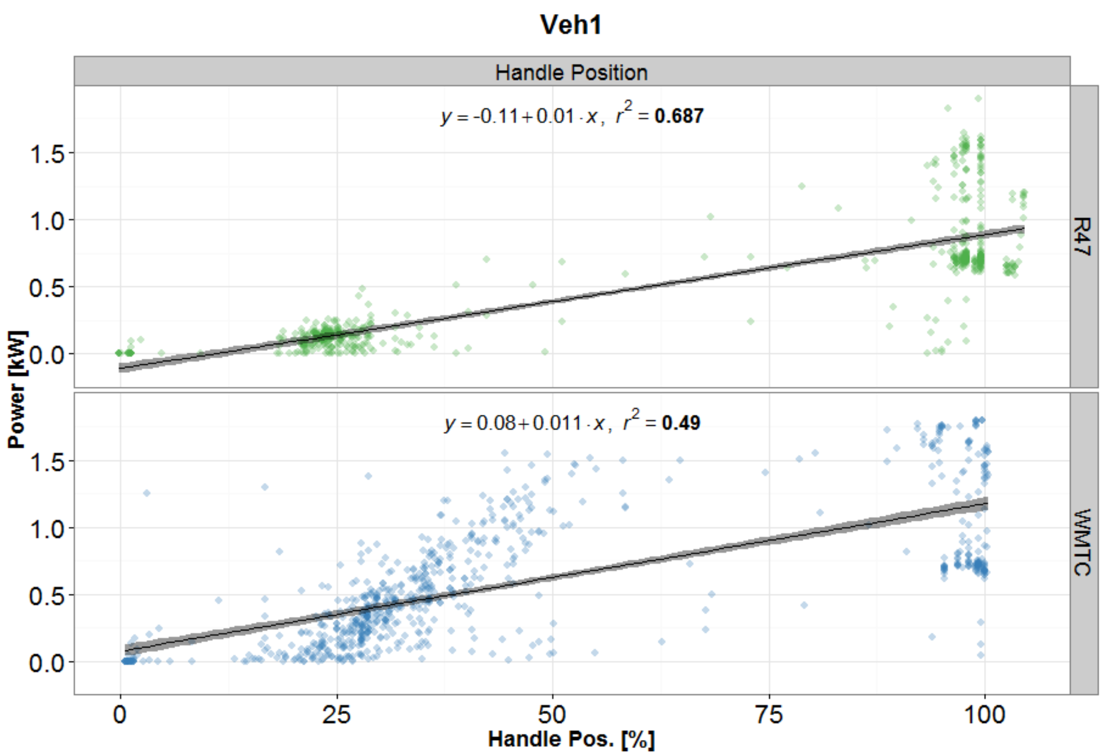


Figure 26. Vehicle 1. Correlation plots of power VS handle position.

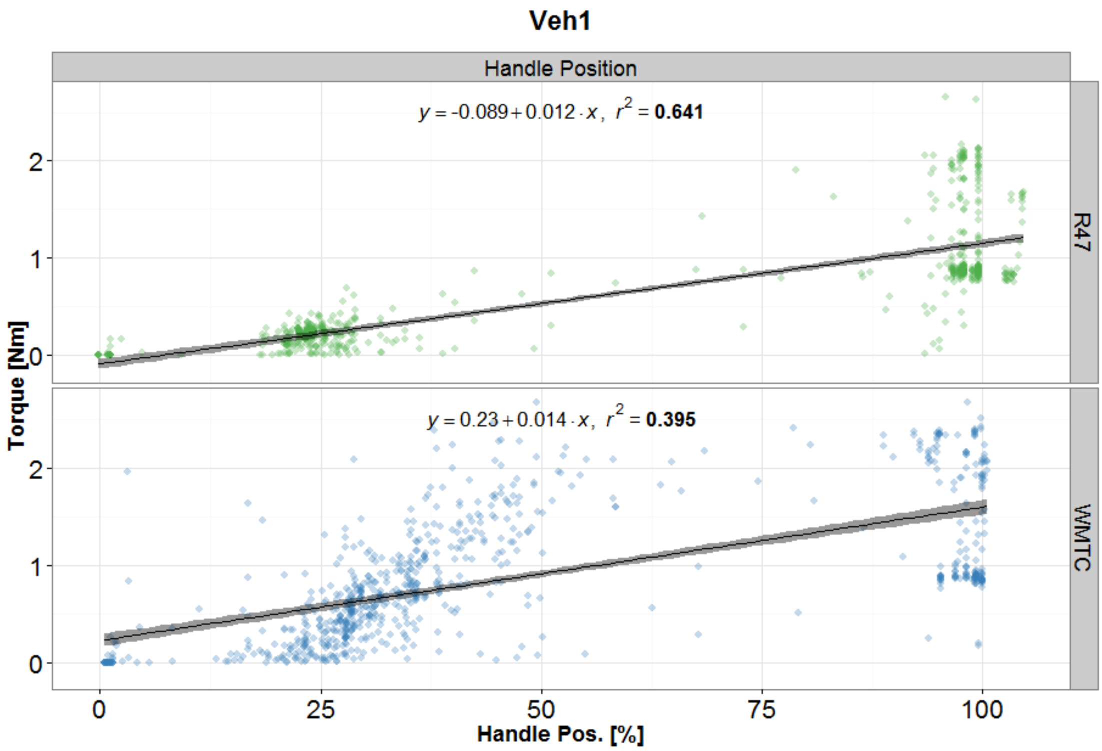


Figure 27. Vehicle 1. Correlation plots of torque VS handle position.

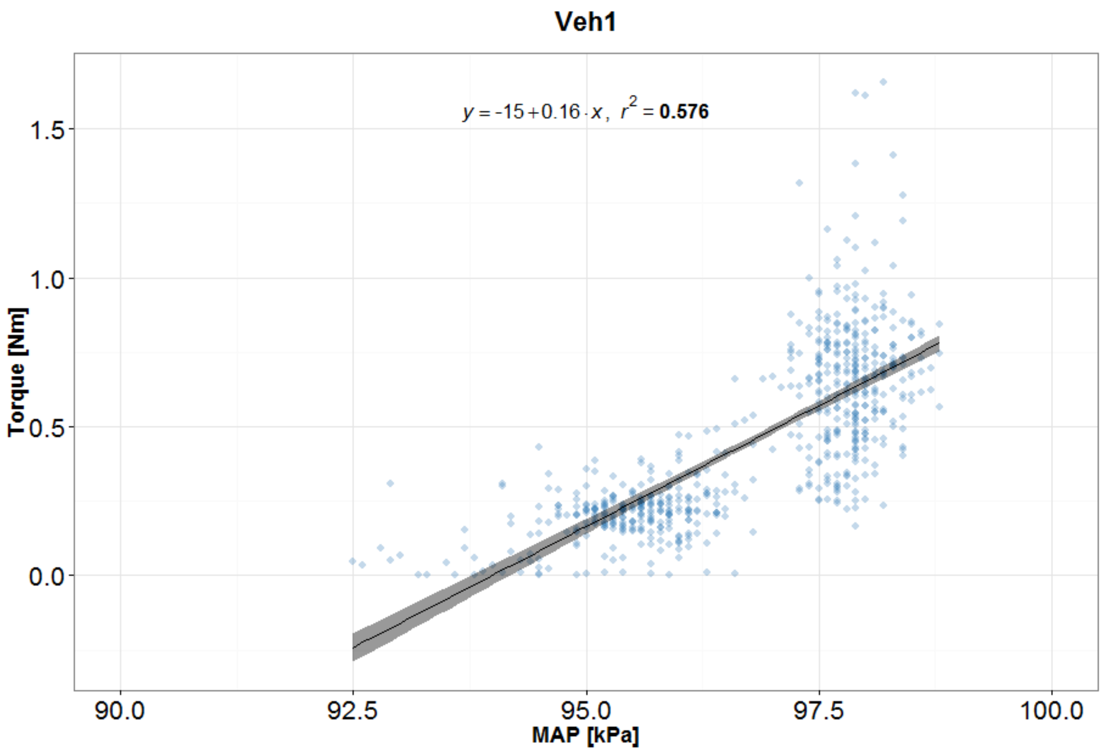


Figure 28. Vehicle 1. Correlation plots of torque VS MAP.

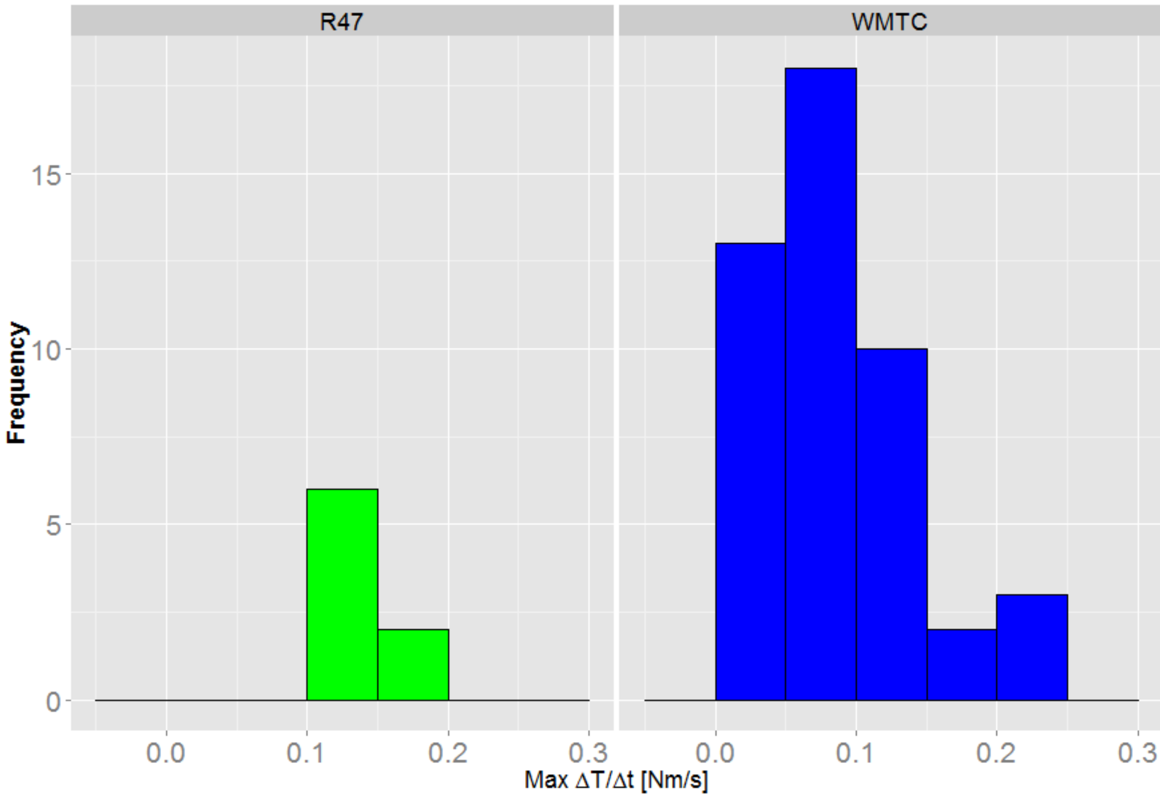


Figure 29. Vehicle 1. Dynamics indicator for the assessment of the WMTC.

4.2 Vehicle 2

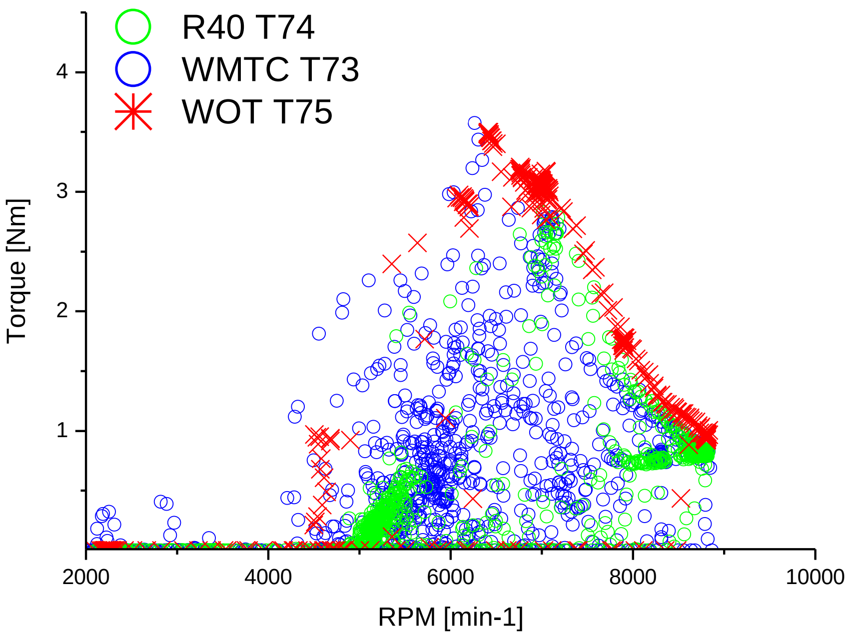


Figure 30. Vehicle 2. Torque (vertical axis) VS engine speed for different driving cycles.

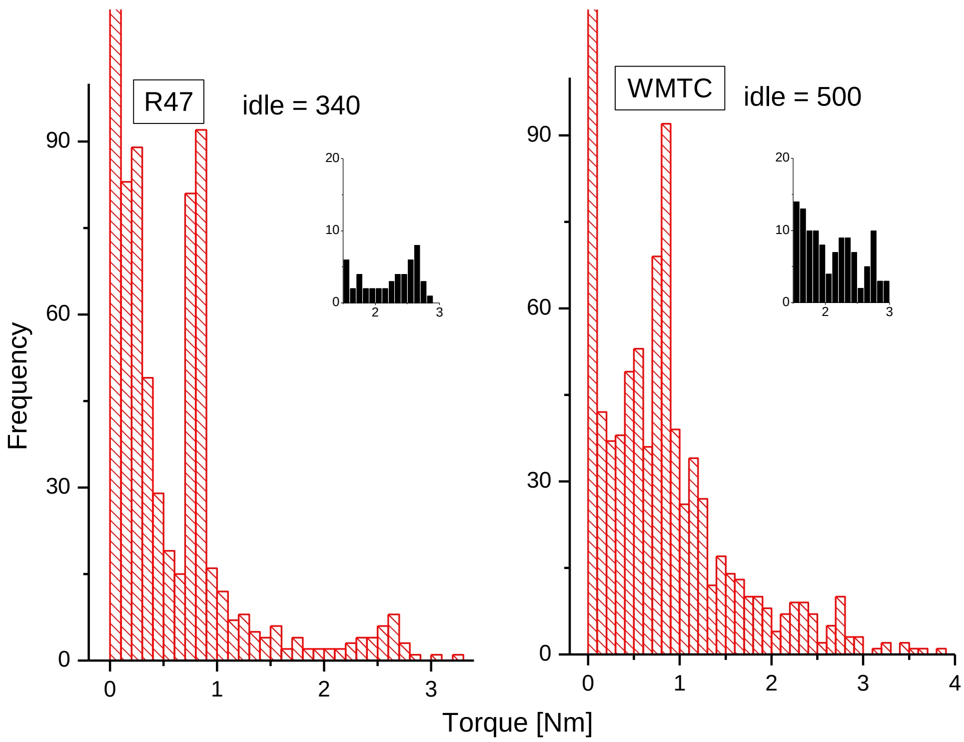


Figure 31. Vehicle 2. Distribution of counts (frequency) for the torque on the horizontal axis.

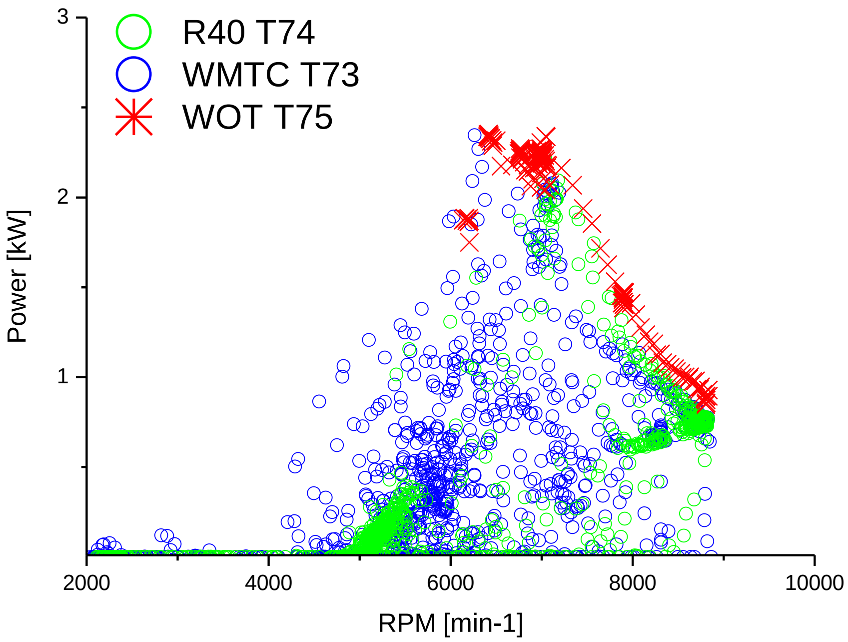


Figure 32. Vehicle 2. Power (vertical axis) VS engine speed for different driving cycles.

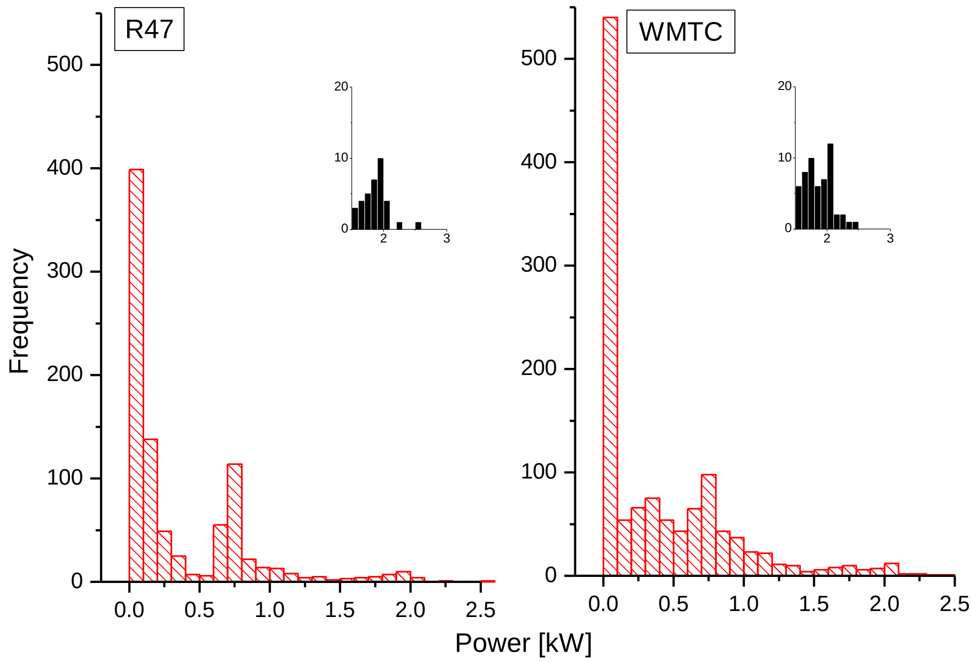


Figure 33. Vehicle 2. Distribution of counts (frequency) for the power on the horizontal axis.

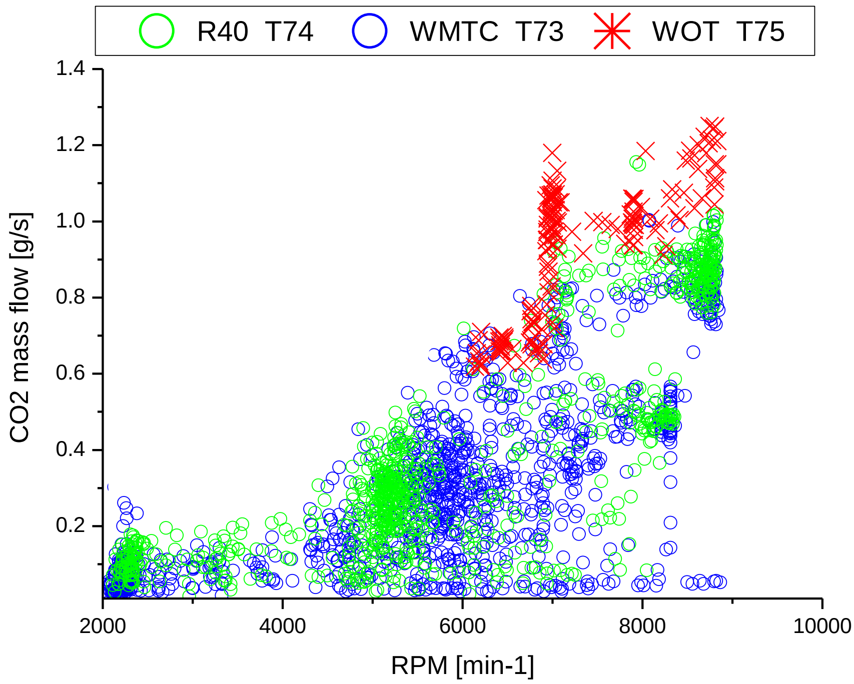


Figure 34. Vehicle 2. CO_2 mass emissions (vertical axis) VS engine speed for different driving cycles.

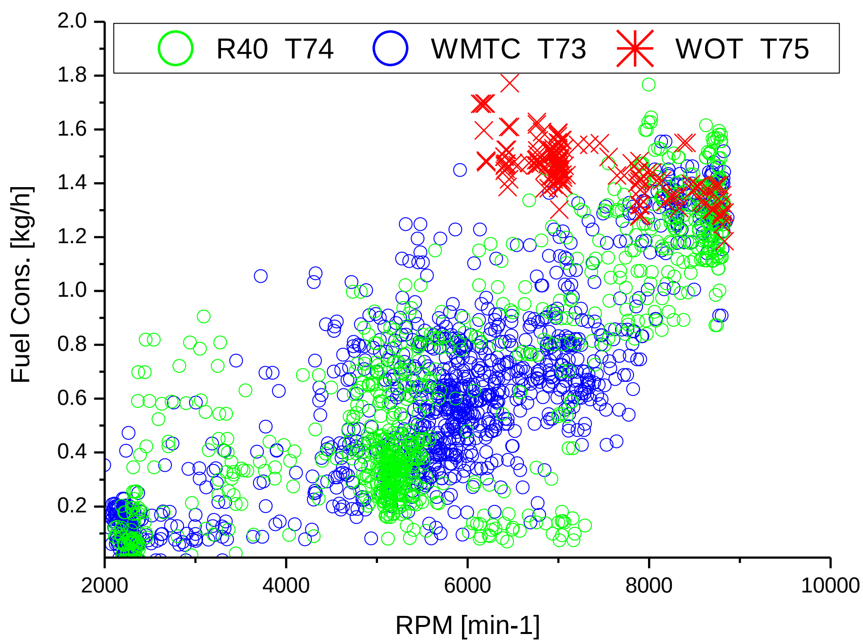


Figure 35. Vehicle 2. Fuel consumption (vertical axis) VS engine speed for different driving cycles.

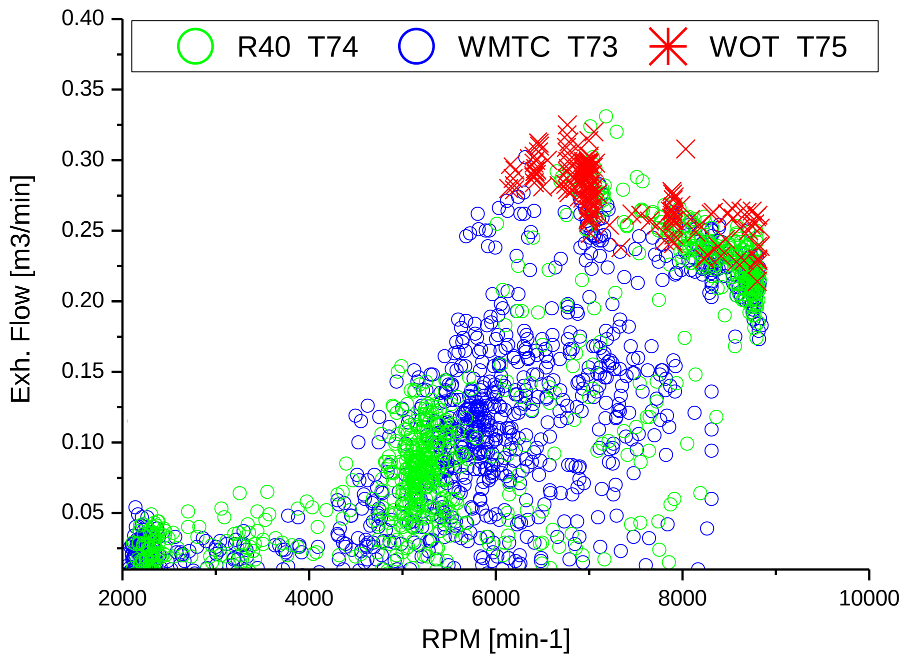


Figure 36. Vehicle 2. Exhaust flow (vertical axis) VS engine speed for different driving cycles.

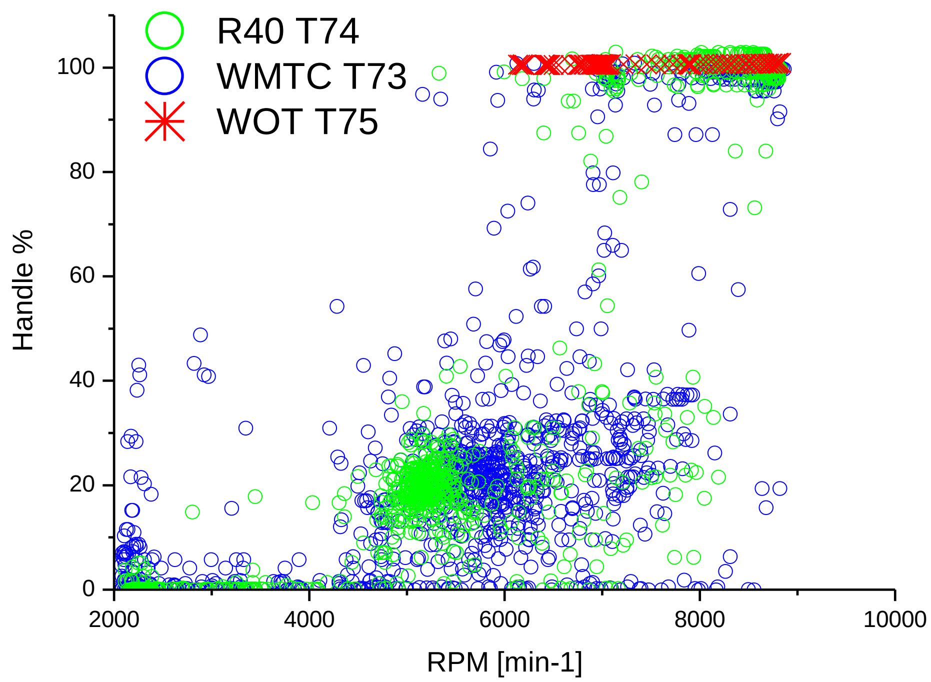


Figure 37. Vehicle 2. Handle position (vertical axis) VS engine speed for different driving cycles.

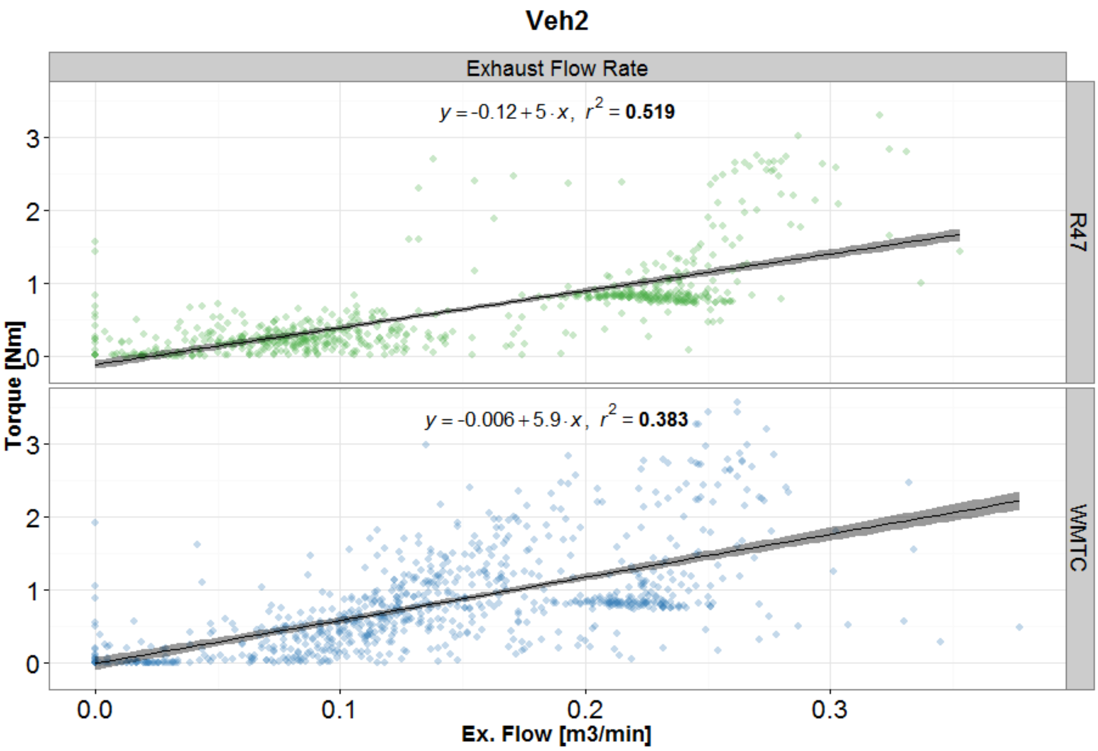


Figure 38. Vehicle 2. Correlation plots of torque VS exhaust flow rate.

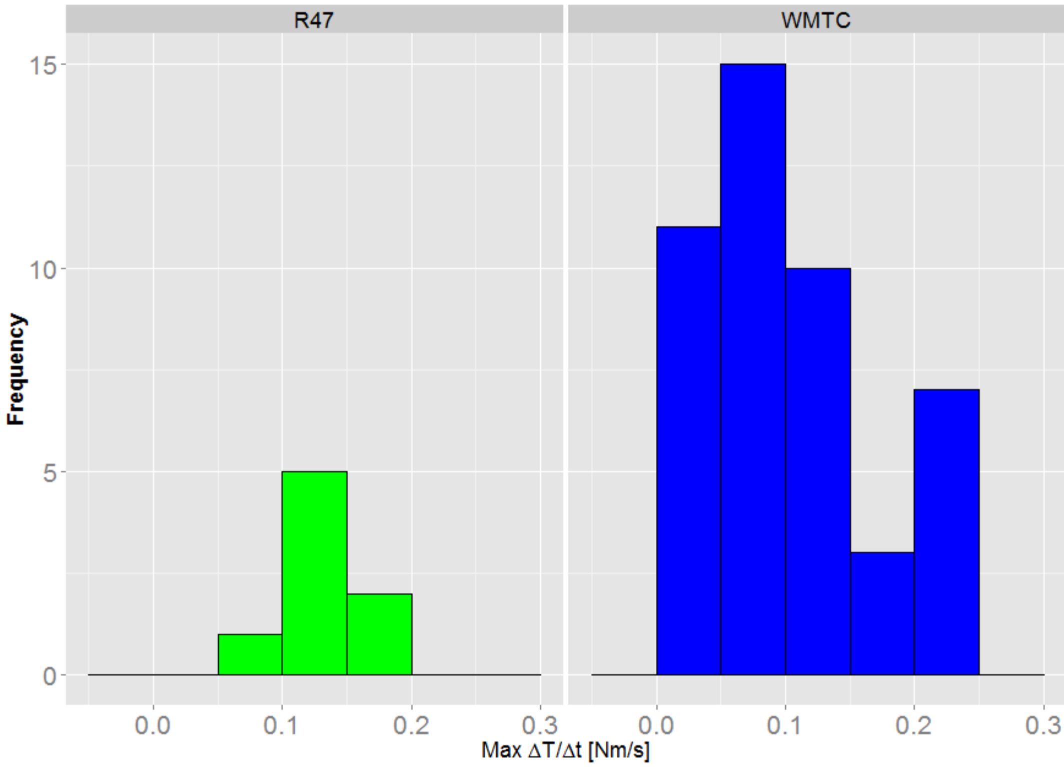


Figure 39. Vehicle 2. *Dynamics* indicator for the assessment of the WMTC.

4.3 Vehicle 3

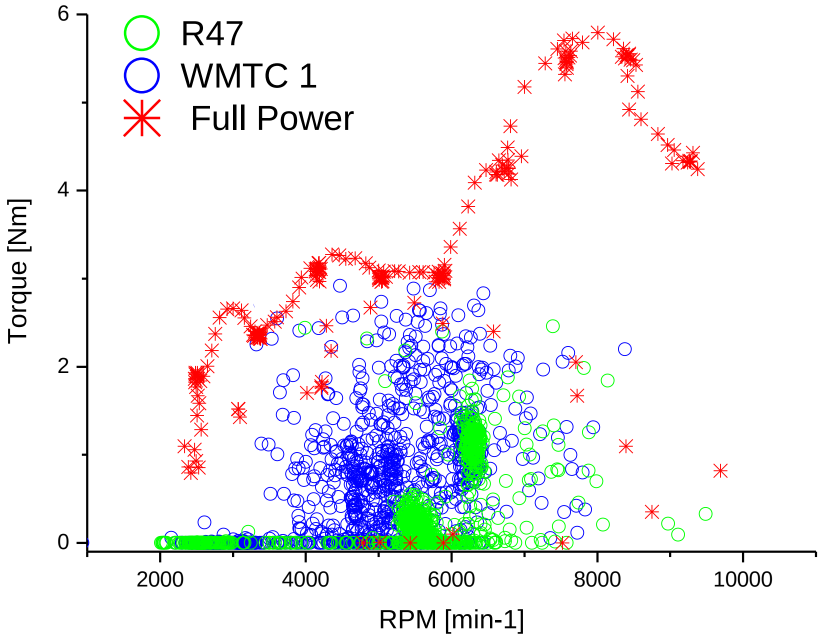


Figure 40. Vehicle 3. Torque (vertical axis) VS engine speed (RPM, min-1) for different driving cycles.

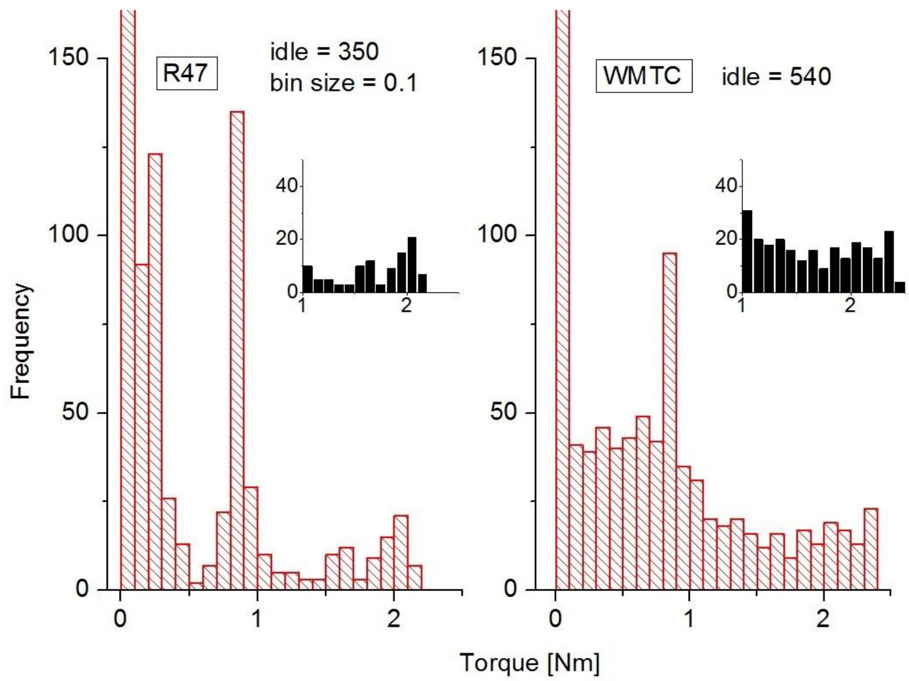


Figure 41. Vehicle 3. Distribution of counts (frequency) for the torque on the horizontal axis.

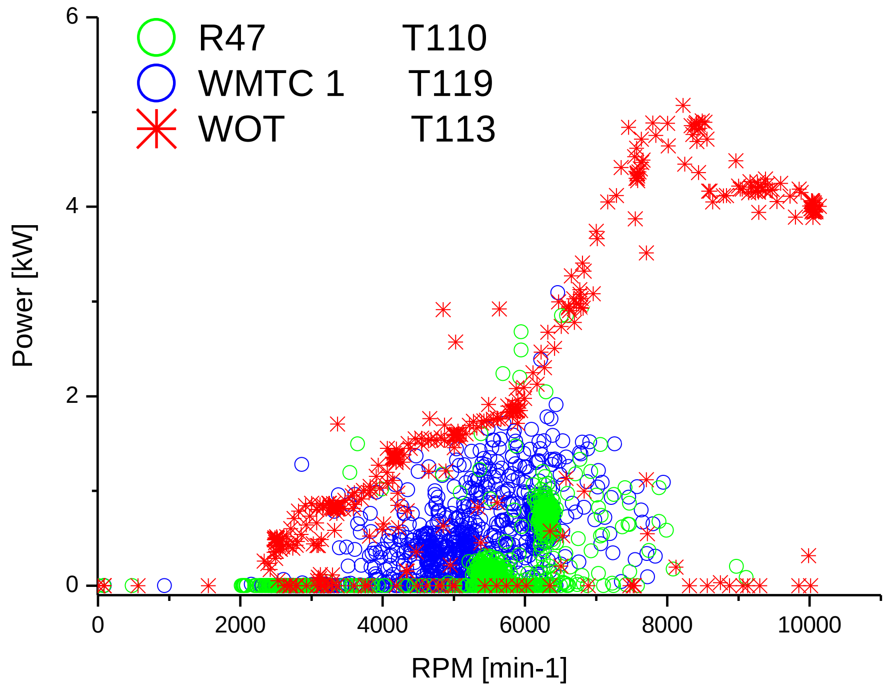


Figure 42. Vehicle 3. Power (vertical axis) VS engine speed for different driving cycles.

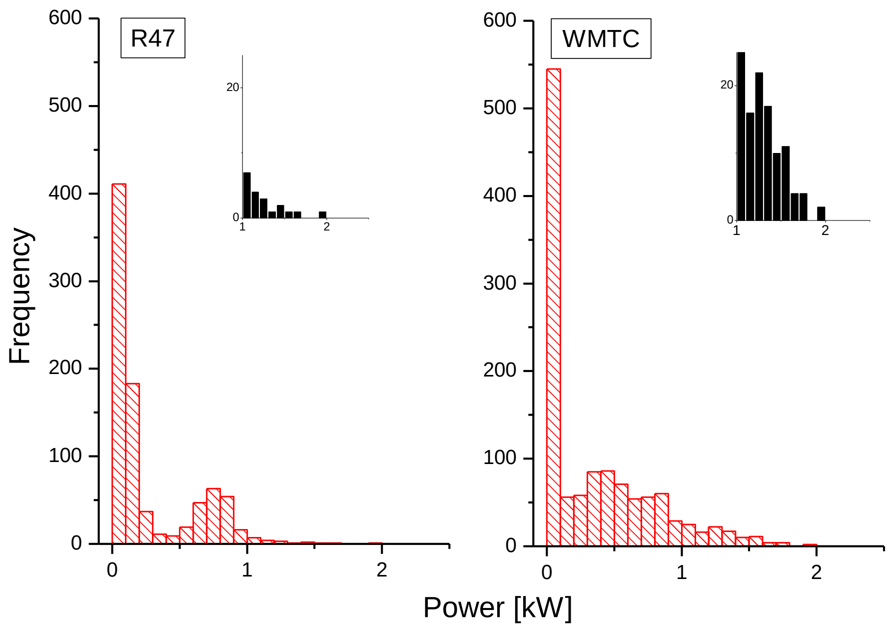


Figure 43. Vehicle 3. Distribution of counts (frequency) for the power on the horizontal axis.

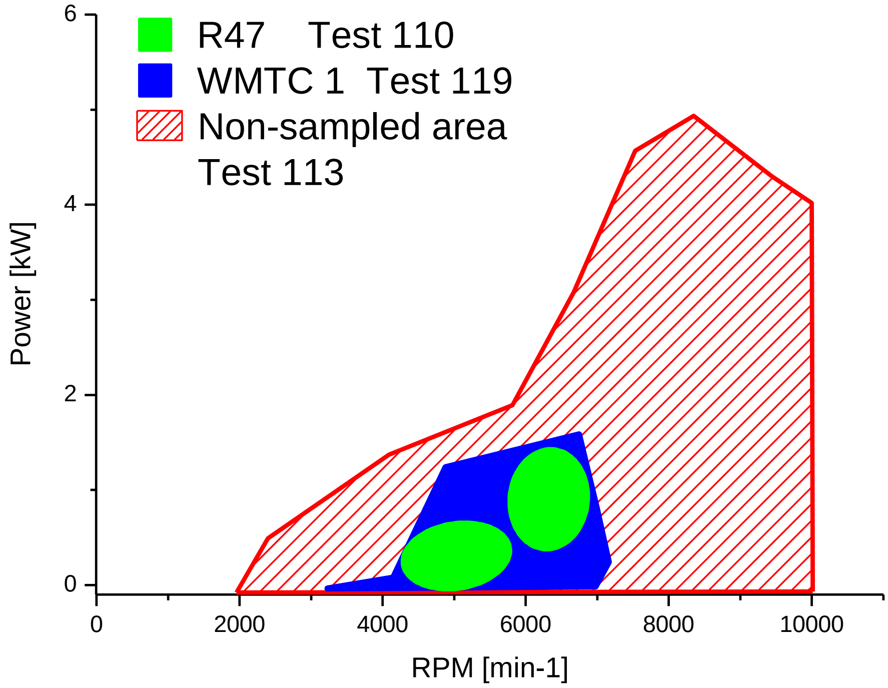


Figure 44. Vehicle 3. Example of sampled areas with the 3 different test cycles. This approach has been used in the determination of the Quality indicator (see Conclusions).

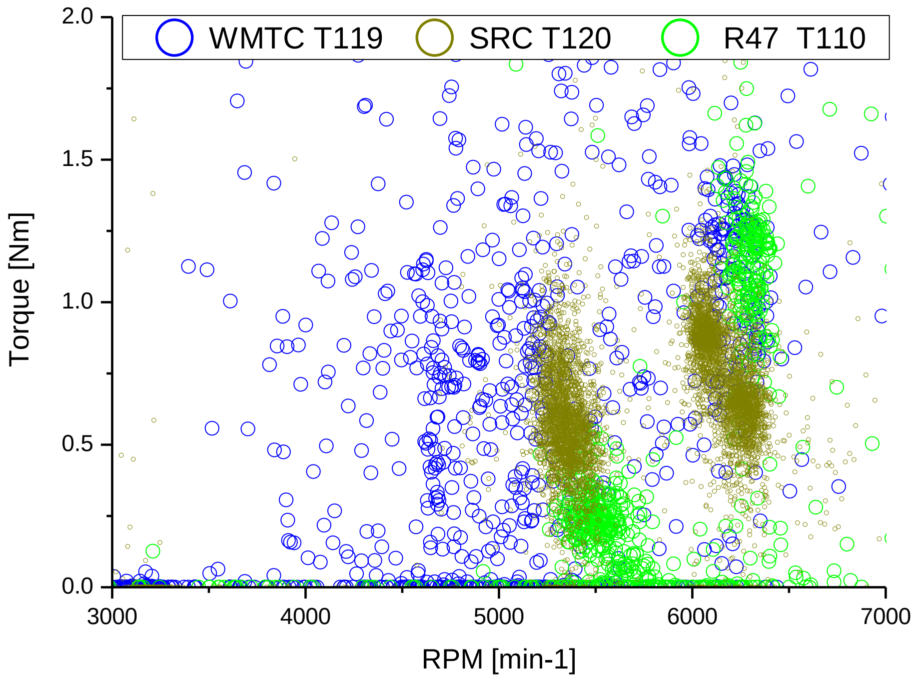


Figure 45. Vehicle 3. Torque (vertical axis) VS engine speed for different driving cycles.

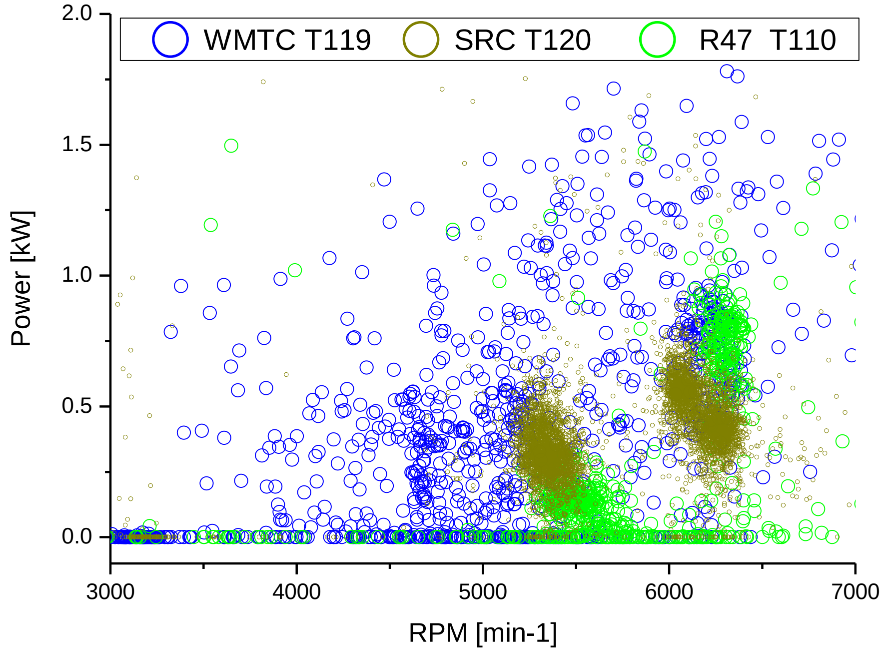


Figure 46. Vehicle 3. Power (vertical axis) VS engine speed for different driving cycles.

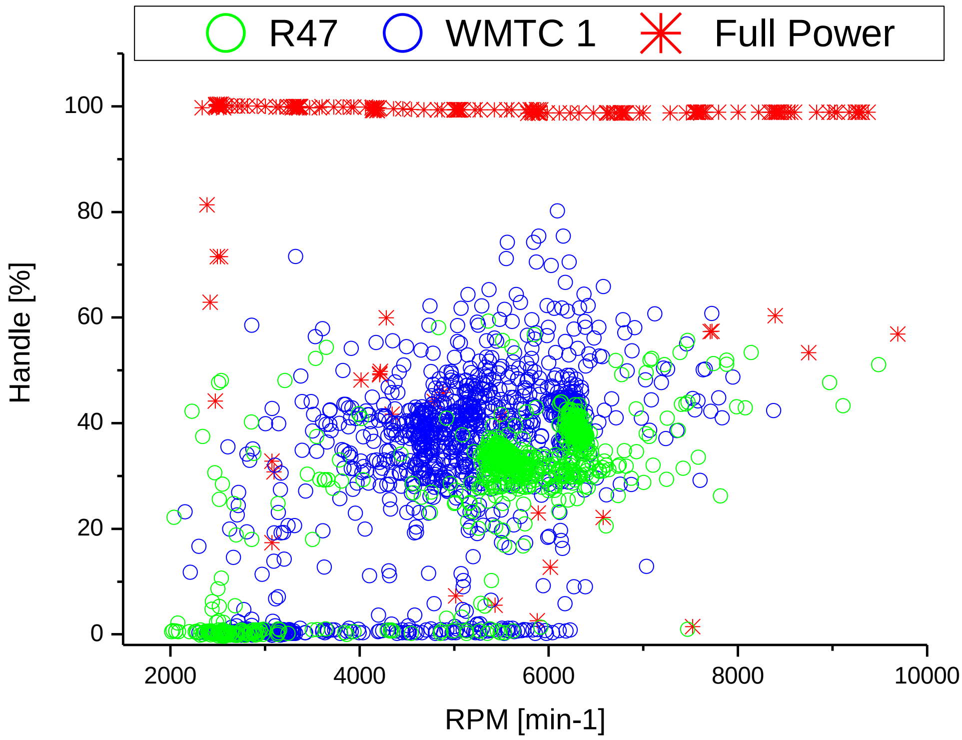


Figure 47. Vehicle 3. Handle position (vertical axis) VS engine speed for different driving cycles.

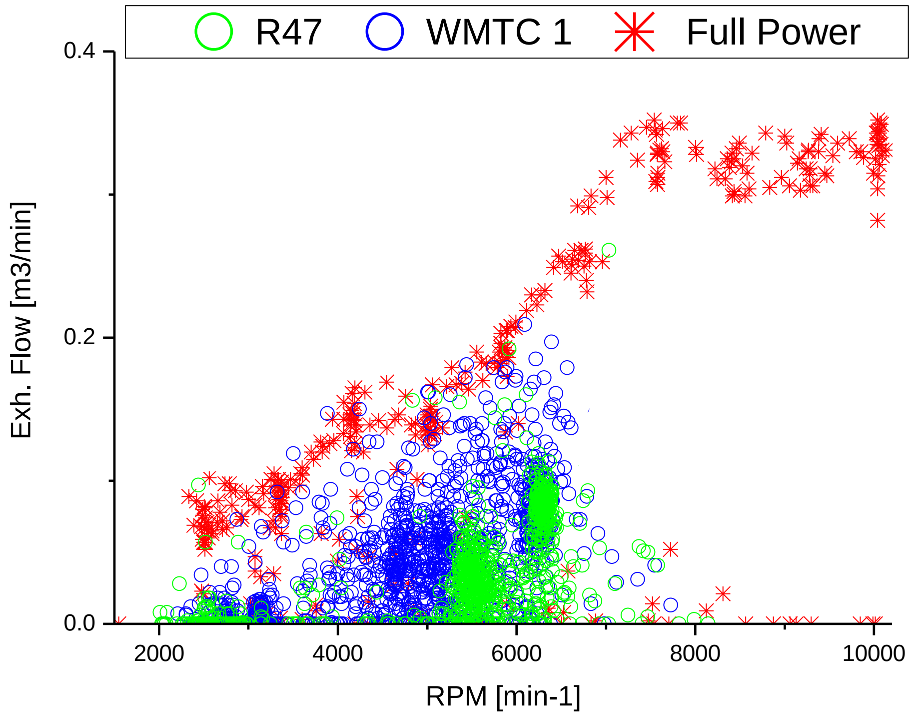


Figure 48. Vehicle 3Exhaust flow (vertical axis) VS engine speed for different driving cycles.

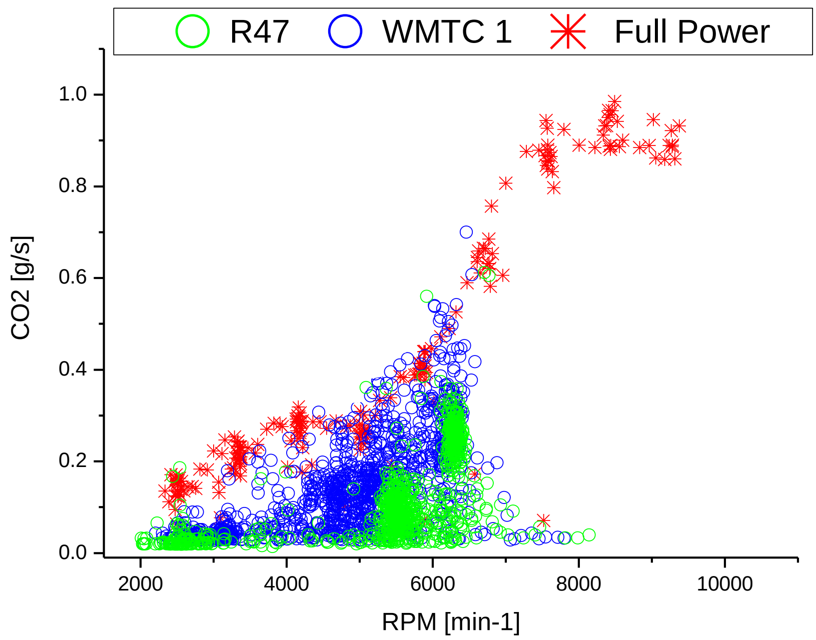


Figure 49. Vehicle 3. CO_2 mass emissions (vertical axis) VS engine speed for different driving cycles.

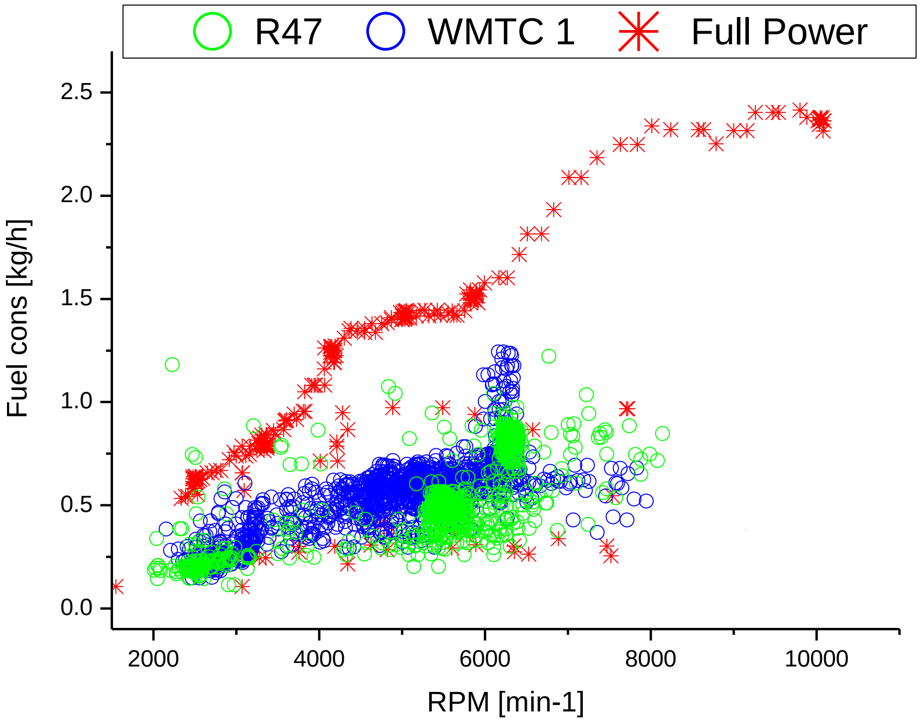


Figure 50. Vehicle 3. Fuel consumption (vertical axis) VS engine speed for different driving cycles.

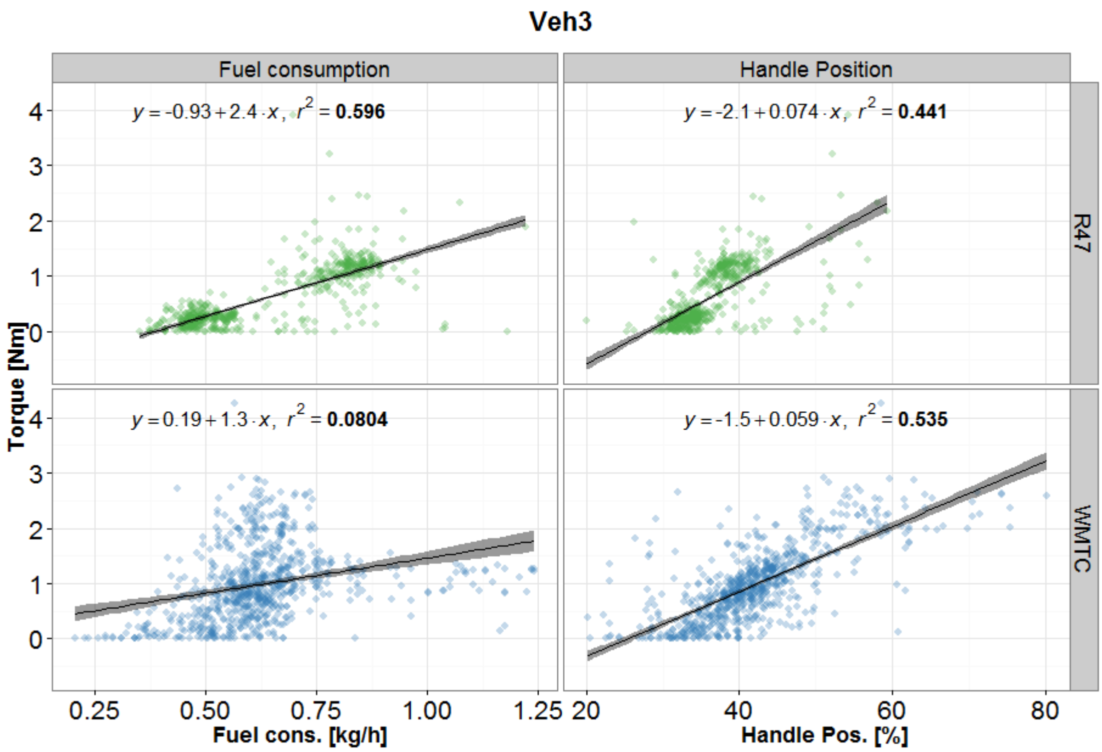


Figure 51. Vehicle 3. Correlation plots of torque VS fuel consumption and handle position.

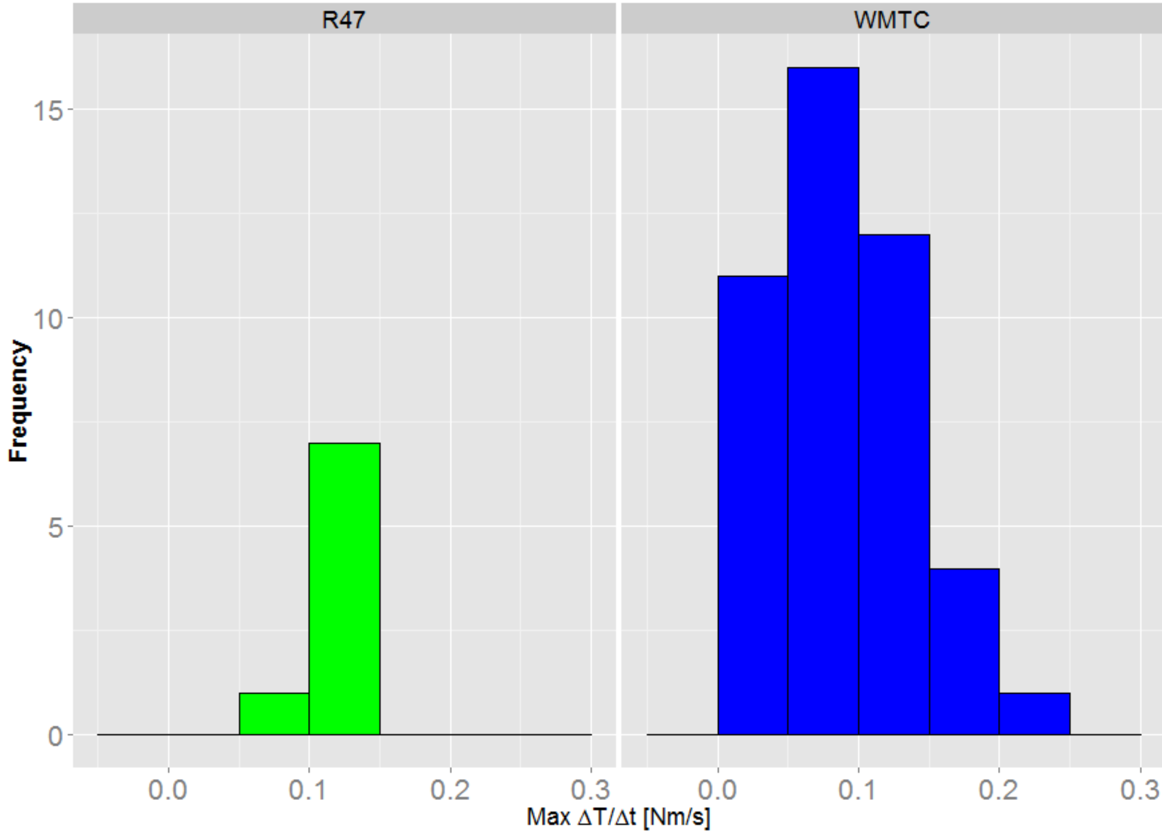


Figure 52. Vehicle 3. *Dynamics* indicator for the assessment of the WMTC.

4.4 Vehicle 4

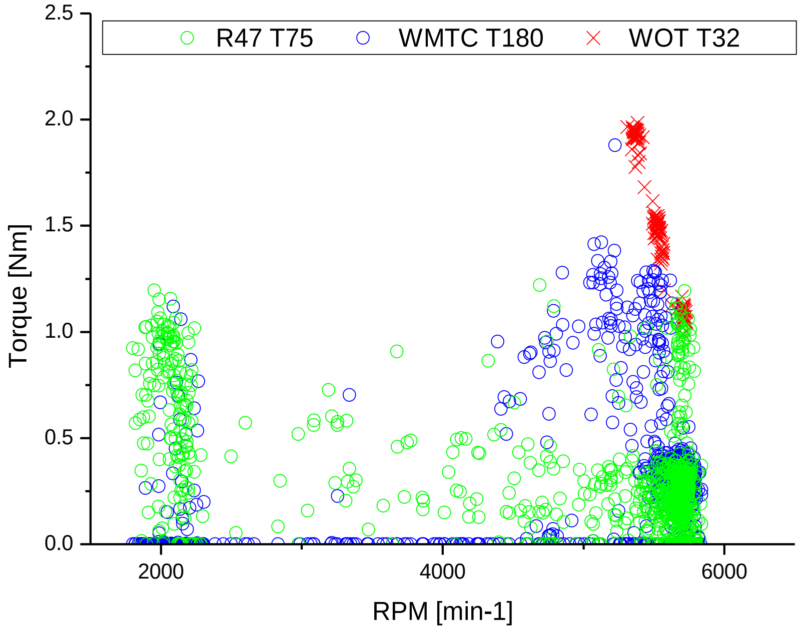


Figure 53. Vehicle 4. Torque (vertical axis) VS engine speed (RPM, min-1) for different driving cycles.

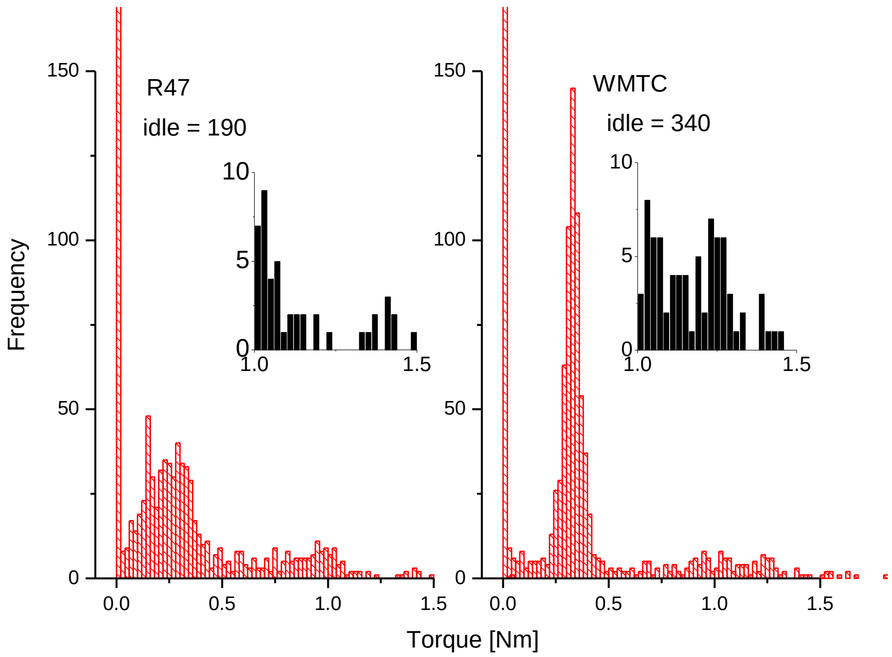


Figure 54. Vehicle 4. Distribution of counts (frequency) for the torque on the horizontal axis.

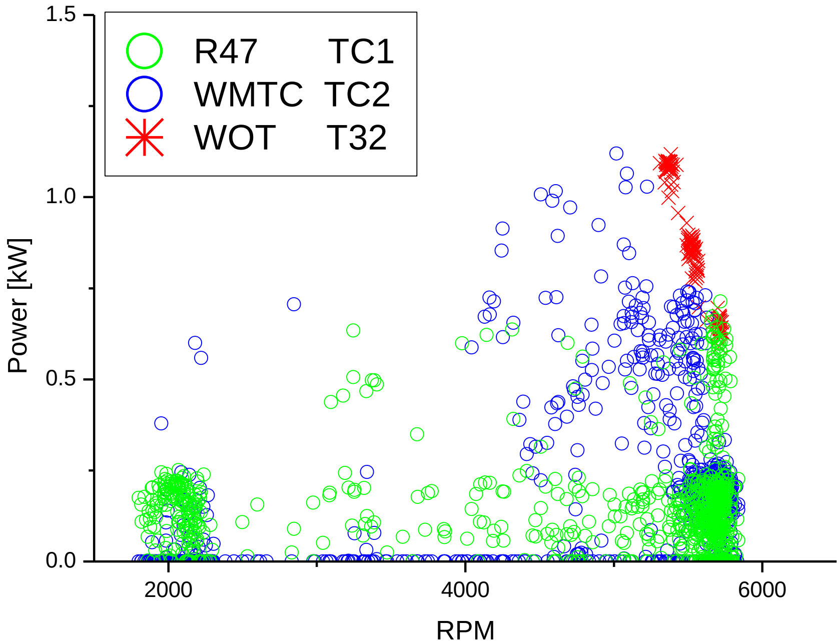


Figure 55. Vehicle 4. Power (vertical axis) VS engine speed for different driving cycles.

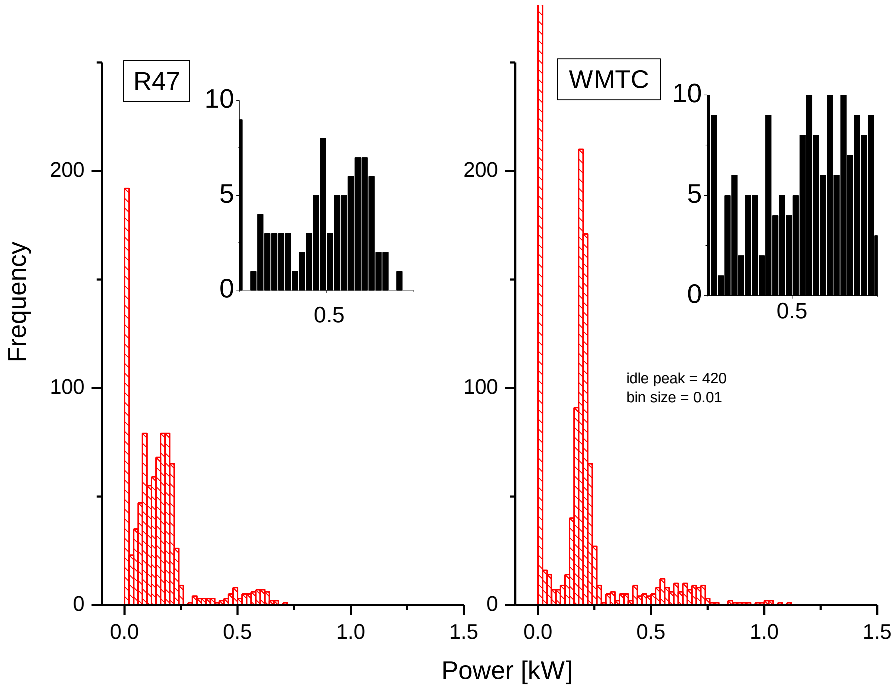


Figure 56. Vehicle 4. Distribution of counts (frequency) for the power on the horizontal axis.

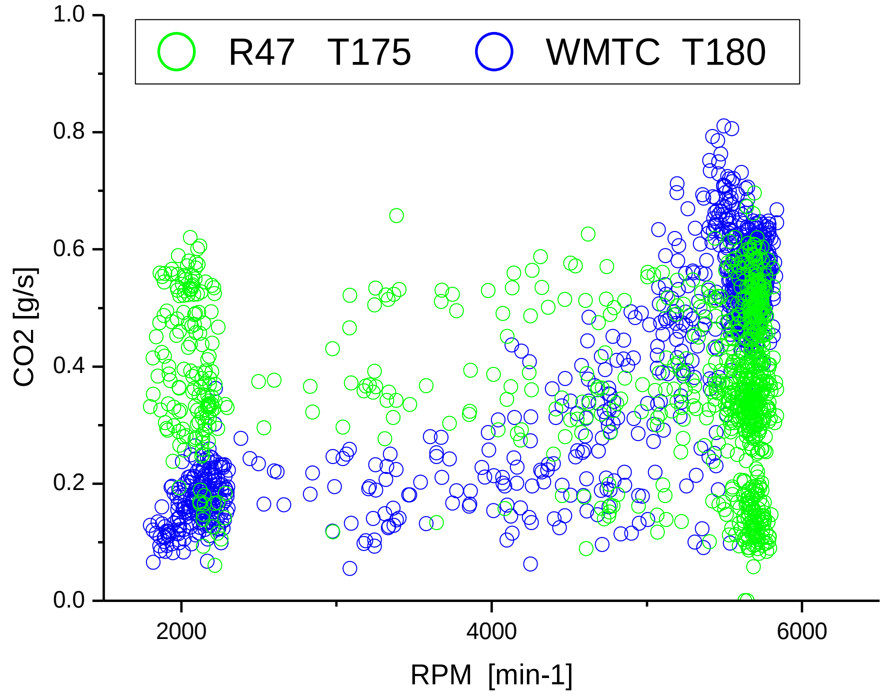


Figure 57. Vehicle 4. CO_2 mass emissions (vertical axis) VS engine speed for different driving cycles.

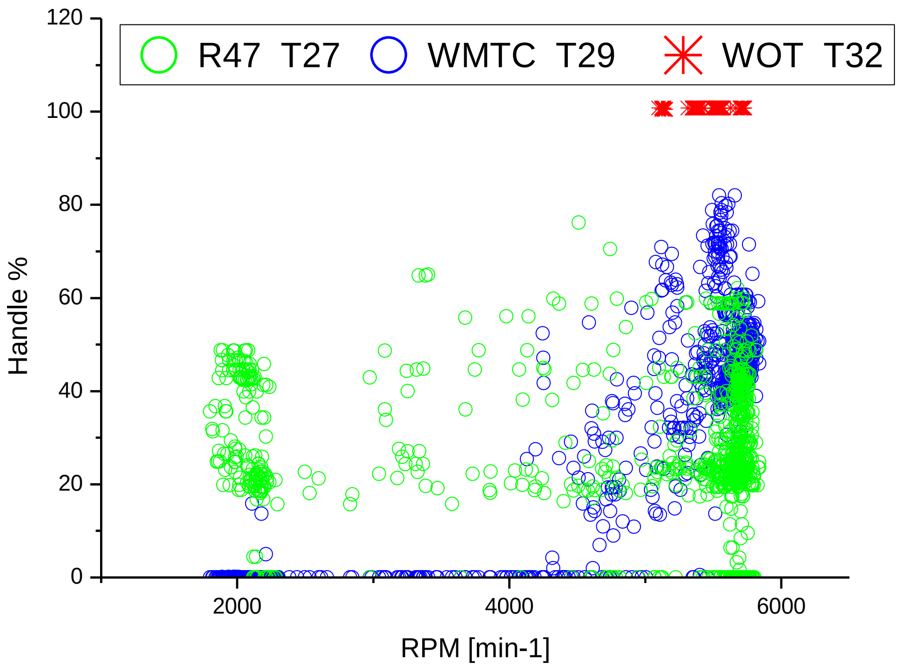


Figure 58. Vehicle 4. Handle position (vertical axis) VS engine speed for different driving cycles.

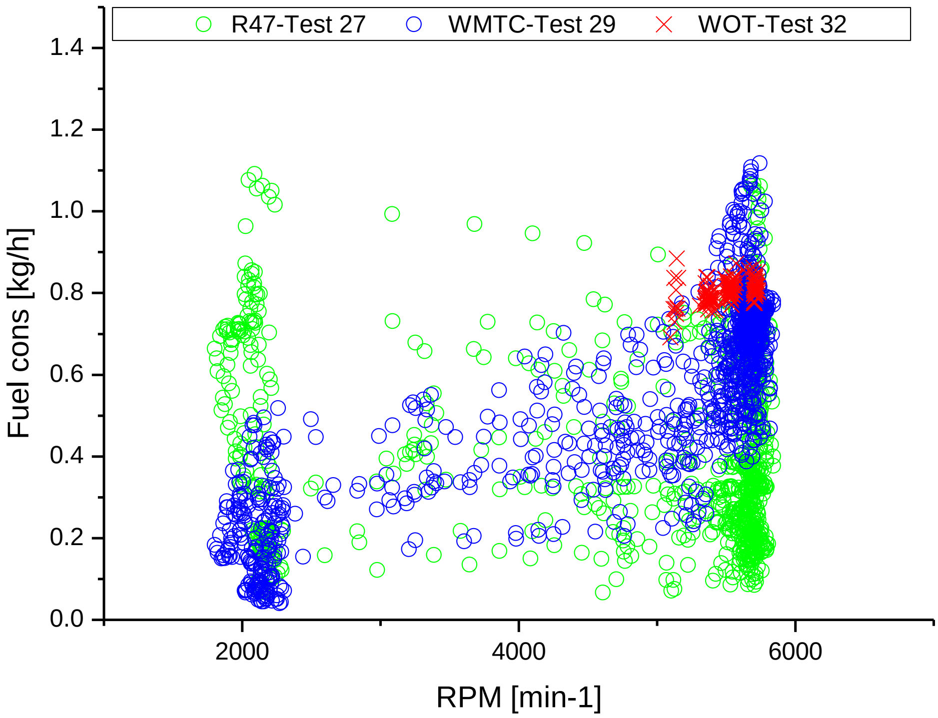


Figure 59. Vehicle 4. Fuel consumption (vertical axis) VS engine speed for different driving cycles.

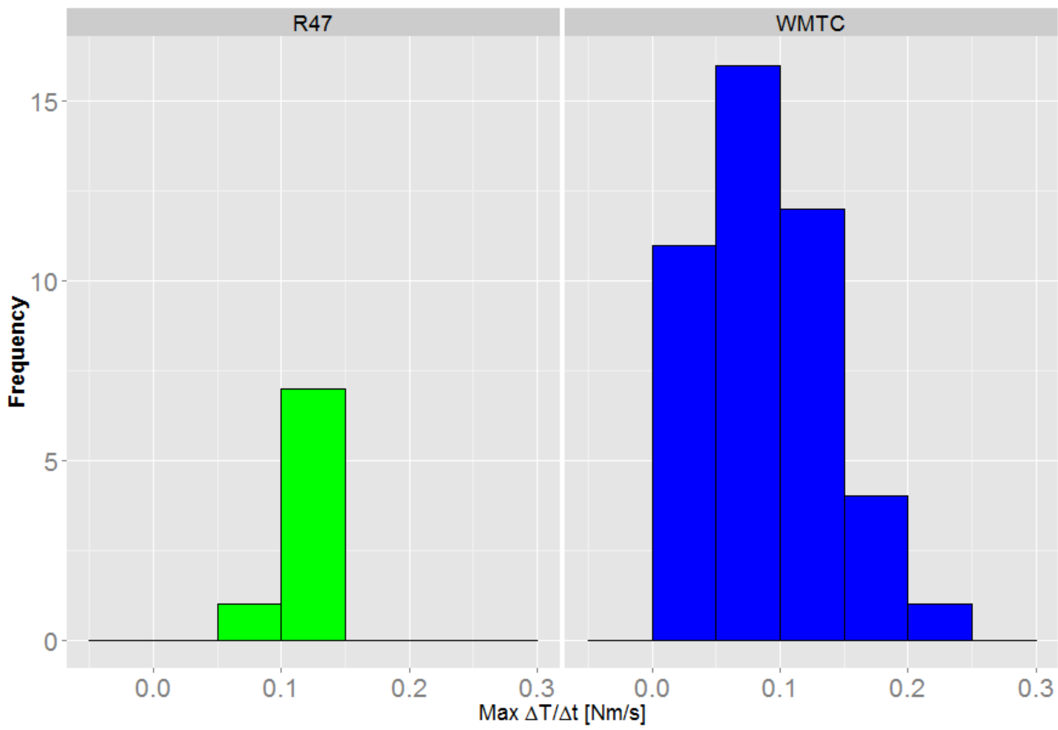


Figure 60. Vehicle 4. *Dynamics* indicator for the assessment of the WMTC.

4.5 Vehicle 5

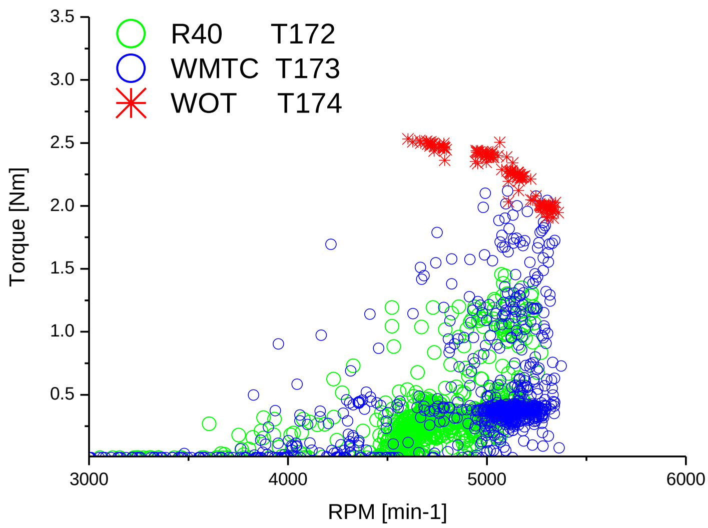


Figure 61. Vehicle 5. Torque (vertical axis) VS engine speed (RPM, min-1) for different driving cycles.

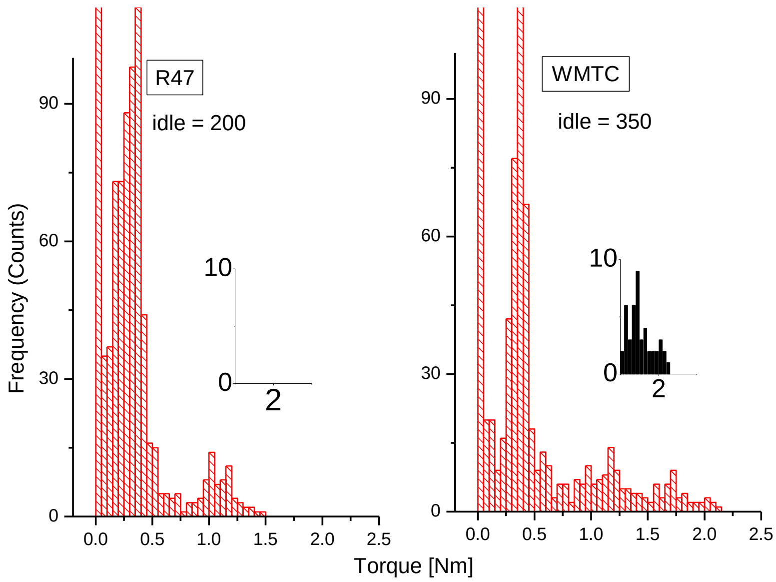


Figure 62. Vehicle 5. Distribution of counts (frequency) for the torque on the horizontal axis.

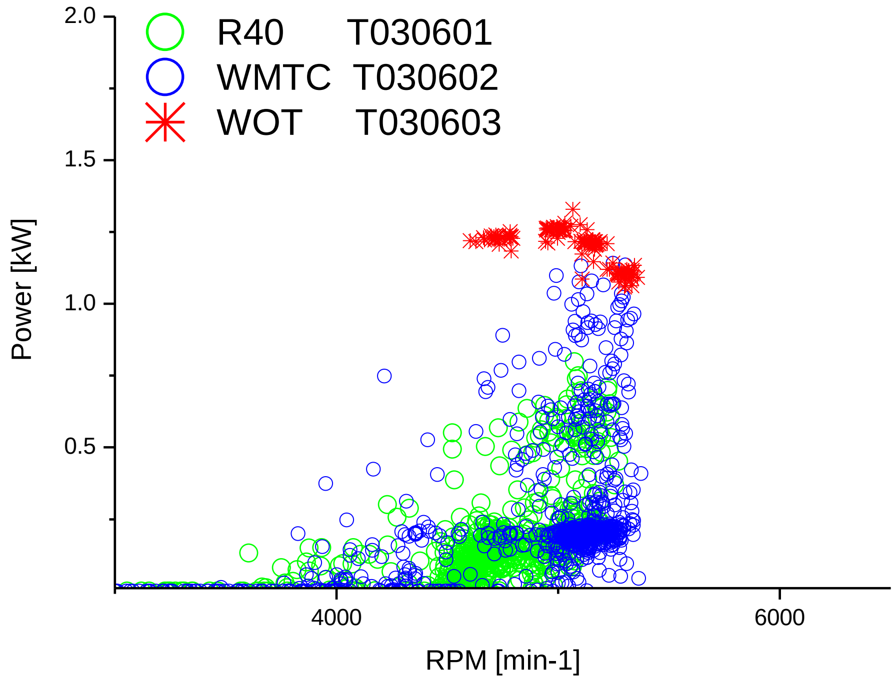


Figure 63. Vehicle 5. Power (vertical axis) VS engine speed for different driving cycles.

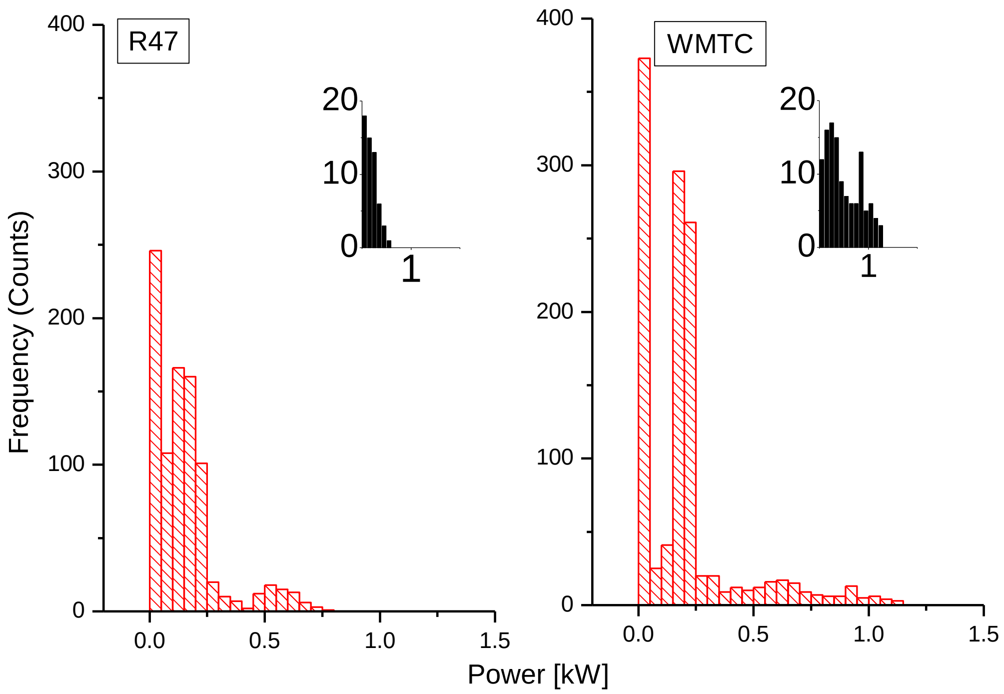


Figure 64. Vehicle 5. Distribution of counts (frequency) for the power on the horizontal axis.

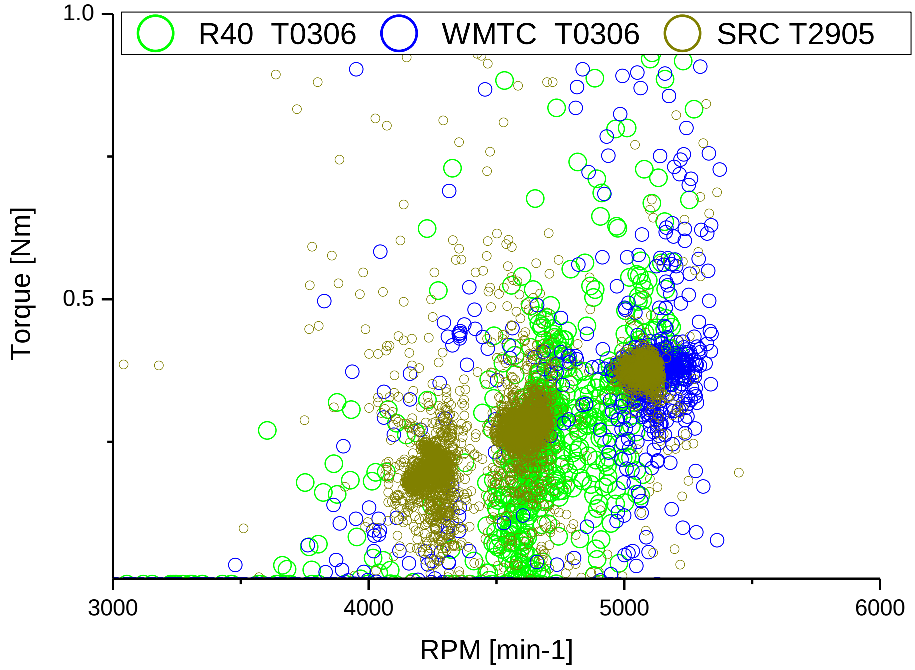


Figure 65. Vehicle 5. Torque (vertical axis) VS engine speed for different driving cycles.

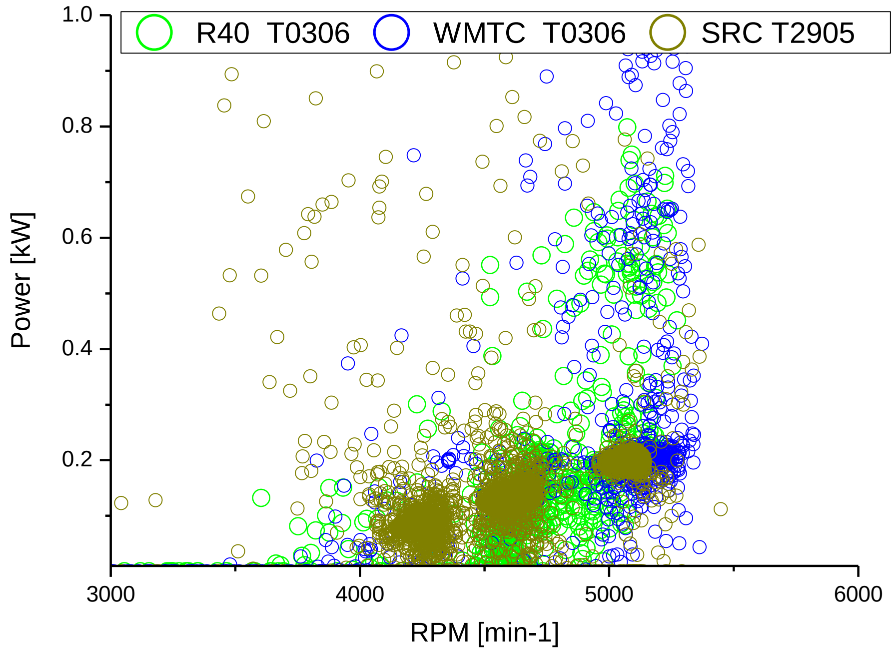


Figure 66. Vehicle 5. Power (vertical axis) VS engine speed for different driving cycles.

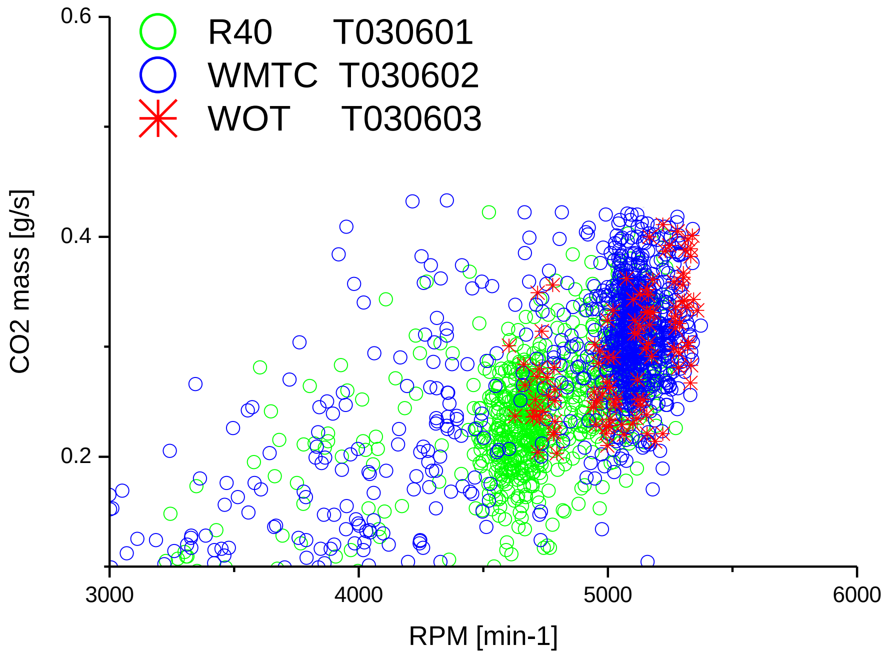


Figure 67. Vehicle 5. CO_2 mass emissions (vertical axis) VS engine speed for different driving cycles.

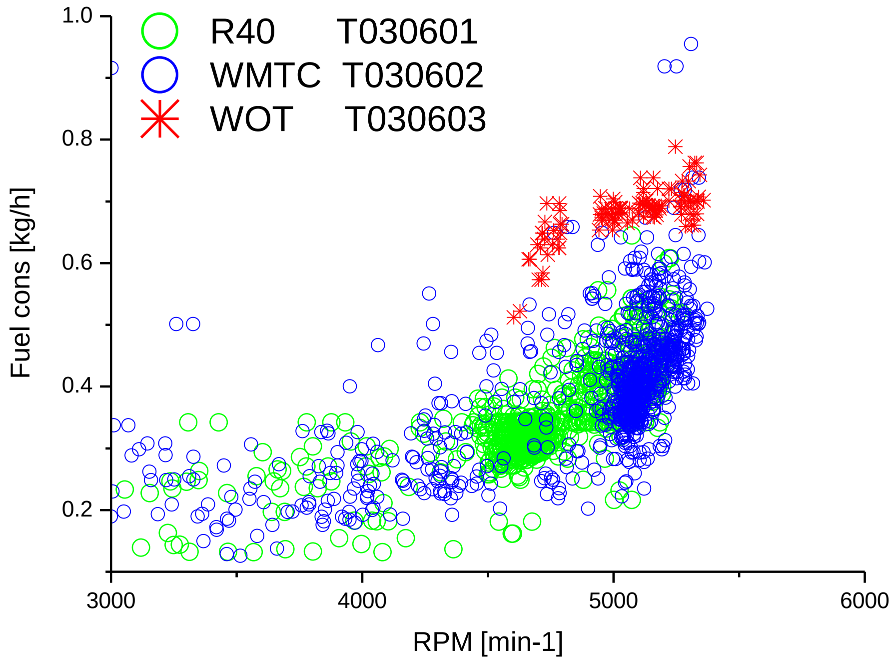


Figure 68. Vehicle 5. Fuel consumption (vertical axis) VS engine speed for different driving cycles.

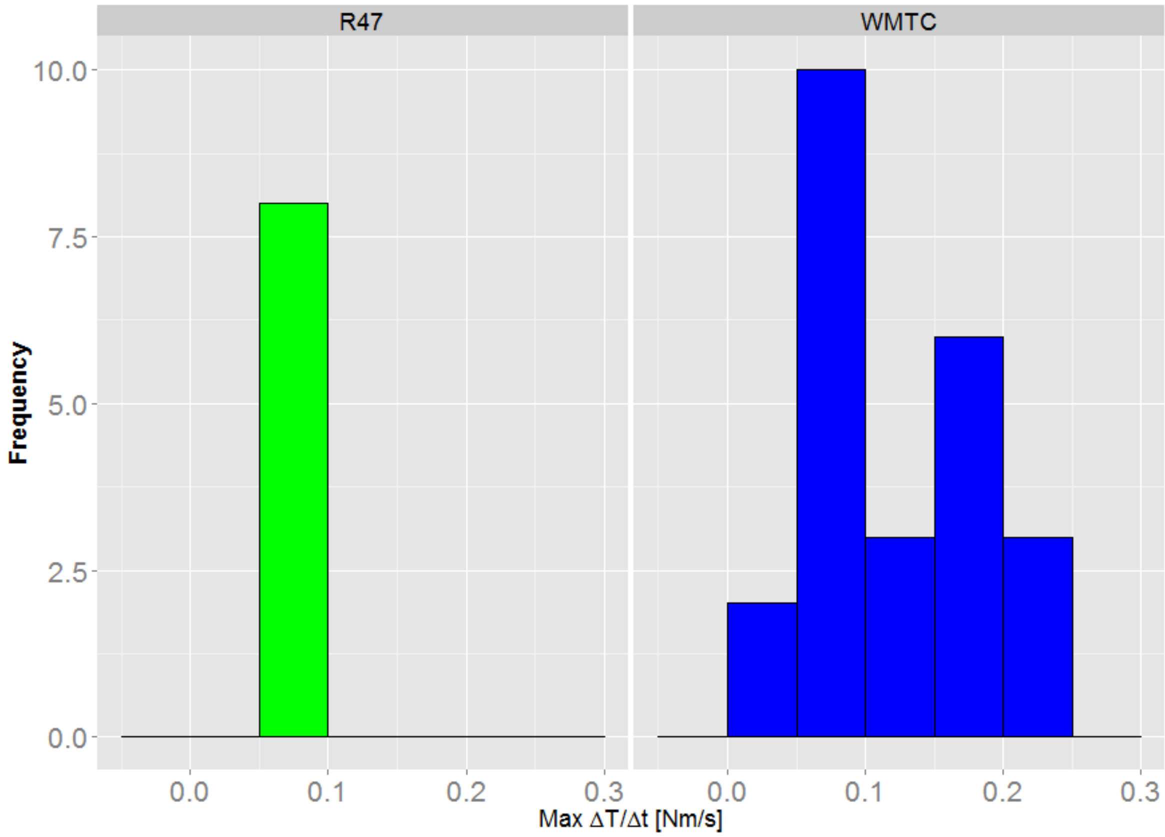


Figure 69. Vehicle 5. *Dynamics* indicator for the assessment of the WMTC.

4.6 Vehicle 6

The driving cycles applicable to this vehicle are the WMTC-1, and the R40 without EUDC (engine displacement <150 cc). The sampling distributions are very similar for the 2 driving cycles, indicating that the quality of sampling points is similar.

Nevertheless, differences can be seen in quantity of sampling points (Frequency plots for torque and power, see Figure 71) indicating that the WMTC is better in terms of engine load coverage than the older R40.

Both driving cycles are far from covering the entire operation range of the vehicle, as revealed by the large empty area below the max torque/ max power curves.

As the vehicle is also able to follow the speed profile of the WMTC 2-1 (its maximum speed is below 100 km/h, but slightly higher than the peak speed of WMTC 2-1), we tested it on this driving cycle as well. Figure 74 shows that the WMTC 2-1 is qualitatively different from the older R40 and that it would be more representative of the vehicle potential, partially covering the empty area under the max torque curve. This is an example of vehicles that **technically can be tested on an upper class of WMTC driving cycle than the one prescribed by the legislation, providing a better coverage of the operation range.**

Similar argument holds for the SRC cycle and its comparison with the WMTC 1 and WMTC 2-1, see Figure 75 and Figure 76.

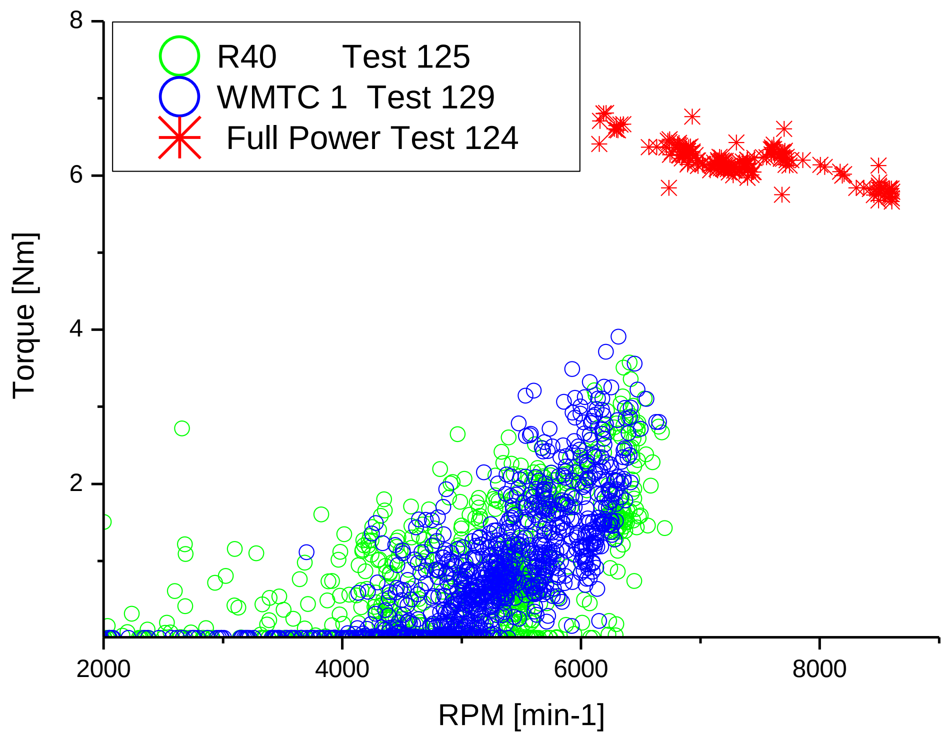


Figure 70. Vehicle 6. Torque (vertical axis) VS engine speed (RPM, min-1) for different driving cycles.

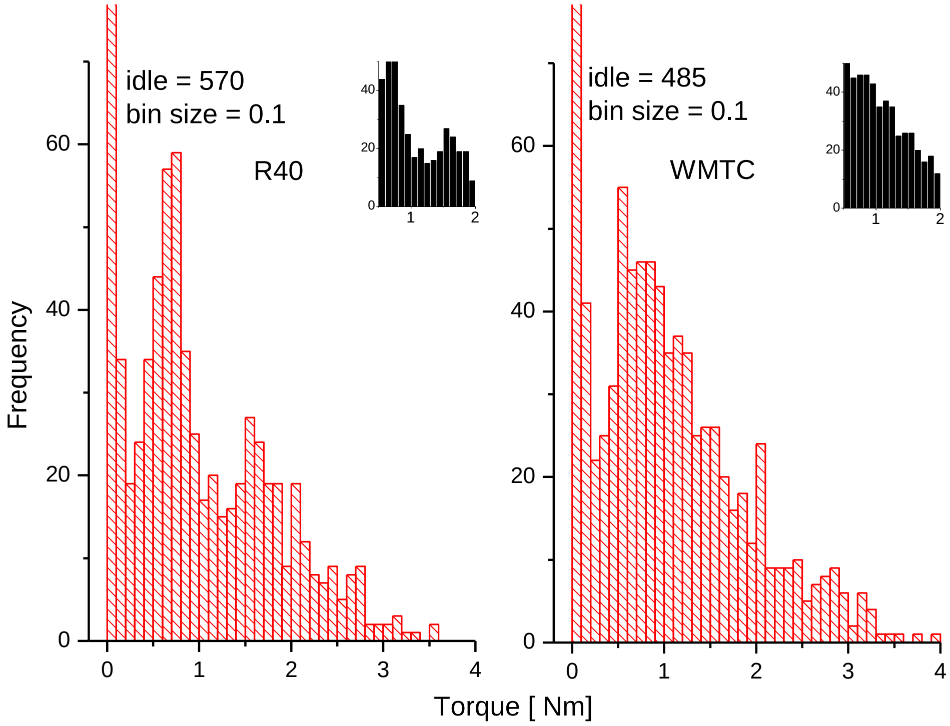


Figure 71. Distribution of counts (frequency) for the torque on the horizontal axis.

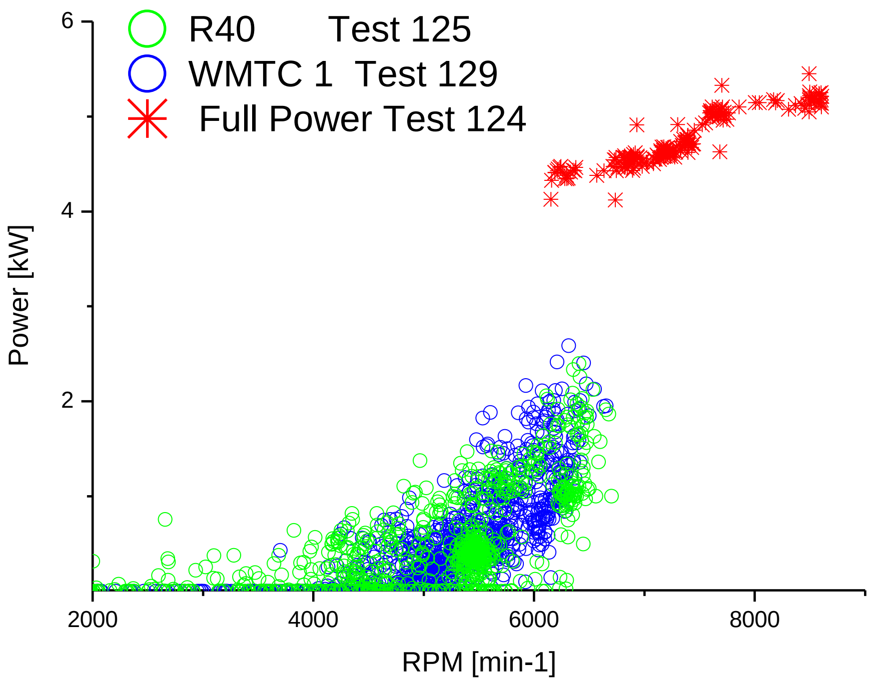


Figure 72. Vehicle 6. Power (vertical axis) VS engine speed for different driving cycles.

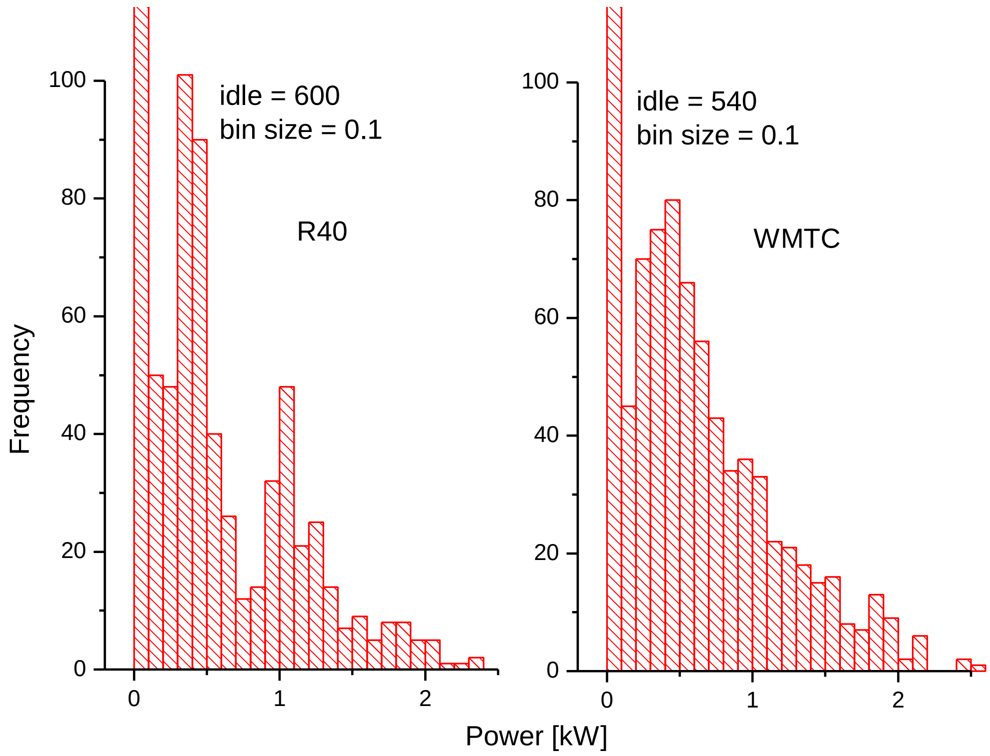


Figure 73. Vehicle 6. Distribution of counts (frequency) for the power on the horizontal axis.

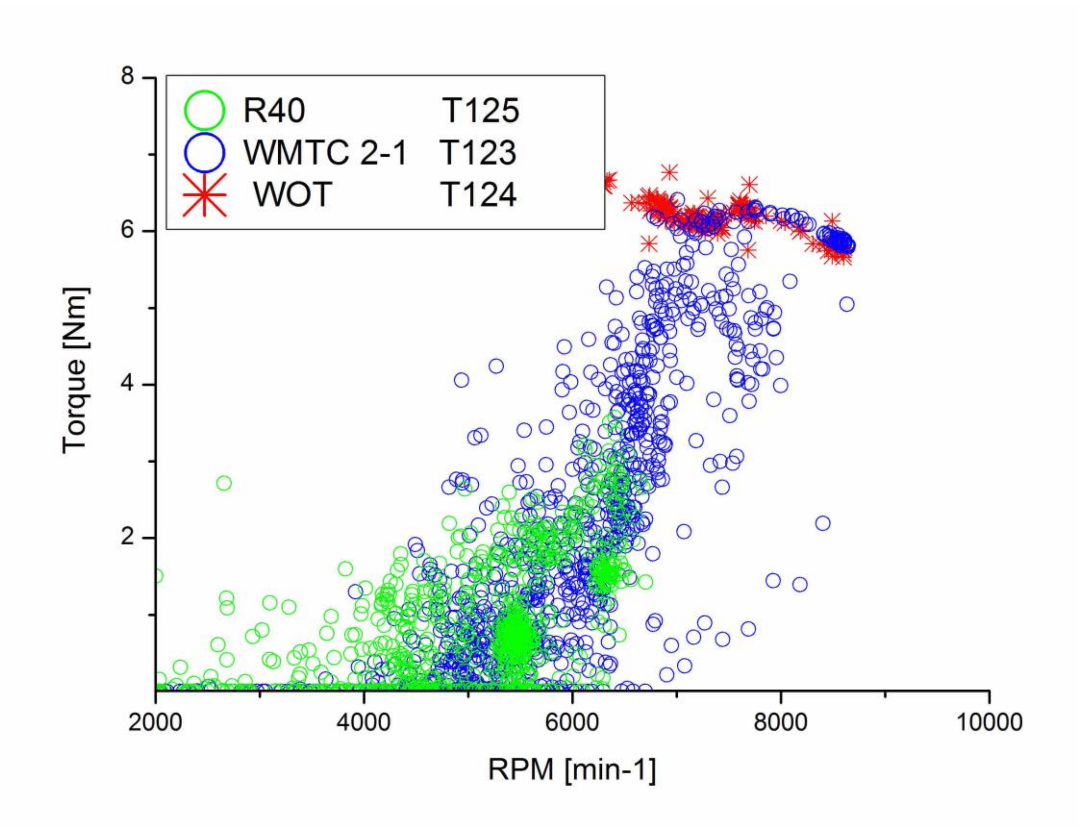


Figure 74. Vehicle 6. Torque (vertical axis) VS engine speed for different driving cycles.

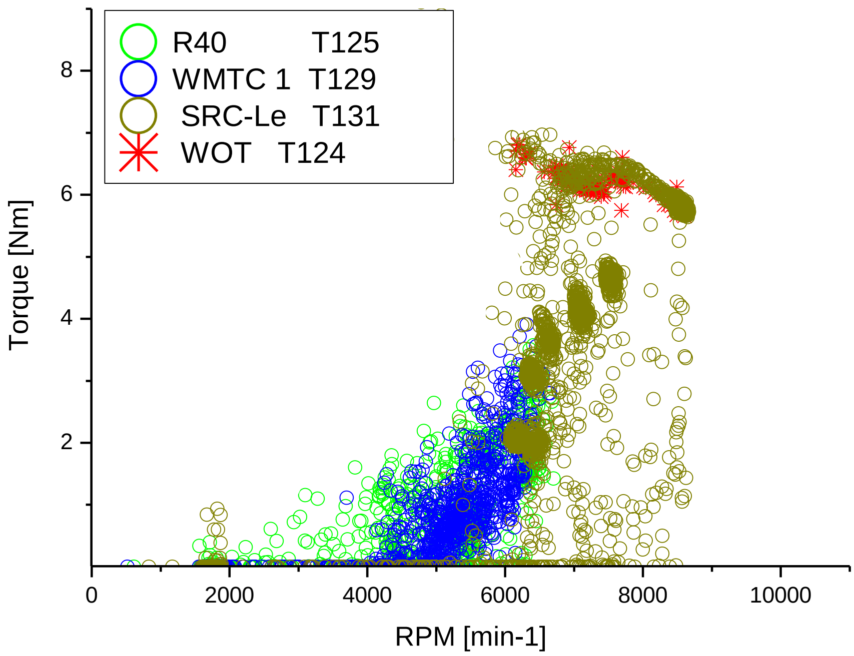


Figure 75. Vehicle 6. Torque (vertical axis) VS engine speed for different driving cycles including the SRC-Le.

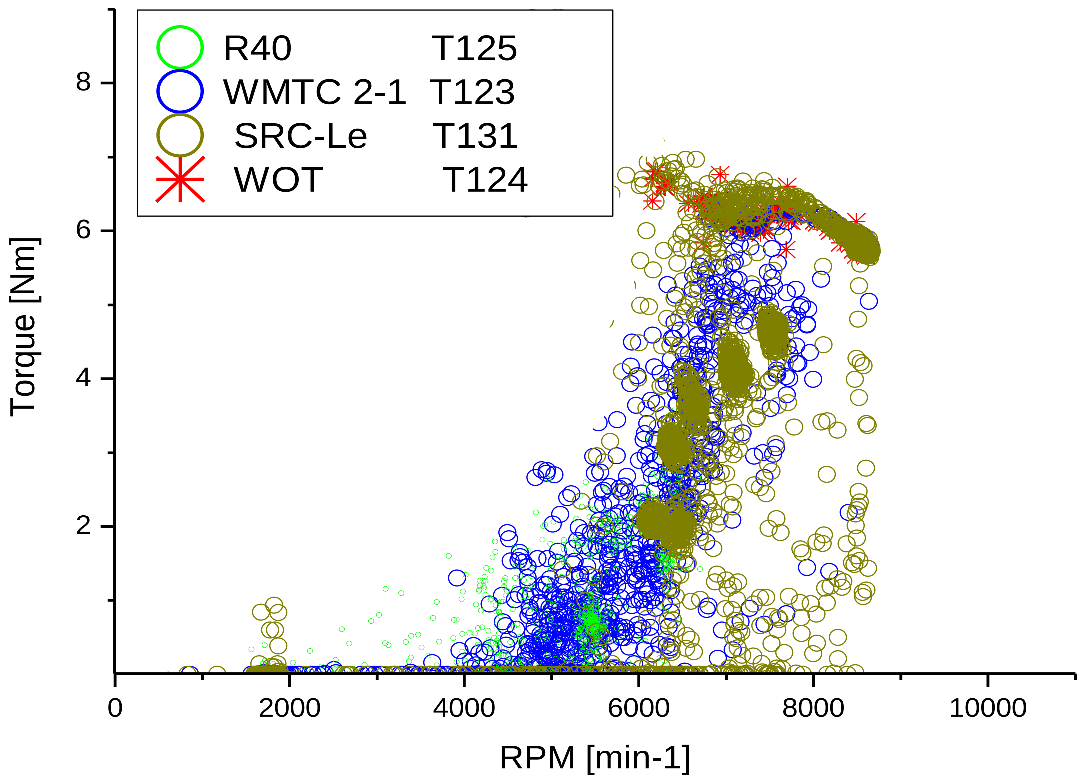


Figure 76. Vehicle 6. Torque (vertical axis) VS engine speed for different driving cycles including the SRC-Le.

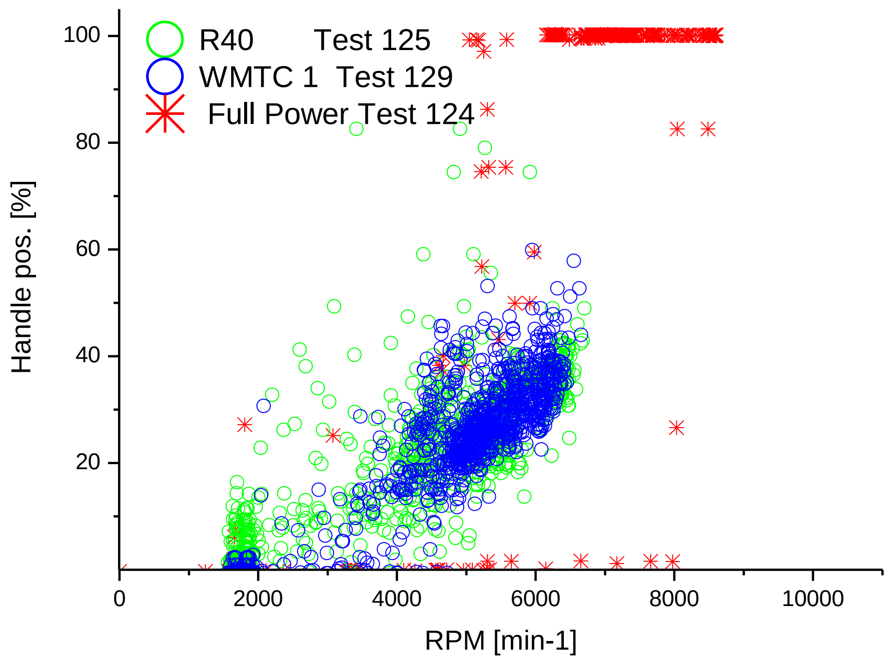


Figure 77. Vehicle 6. Handle position (vertical axis) VS engine speed for different driving cycles.

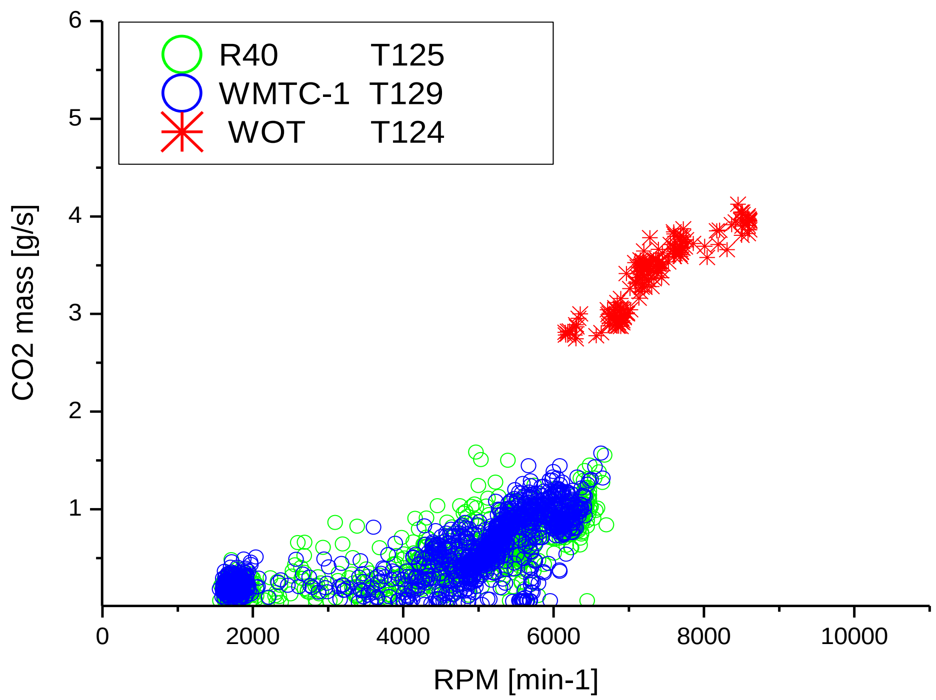


Figure 78. Vehicle 6. CO_2 mass emissions (vertical axis) VS engine speed for different driving cycles.

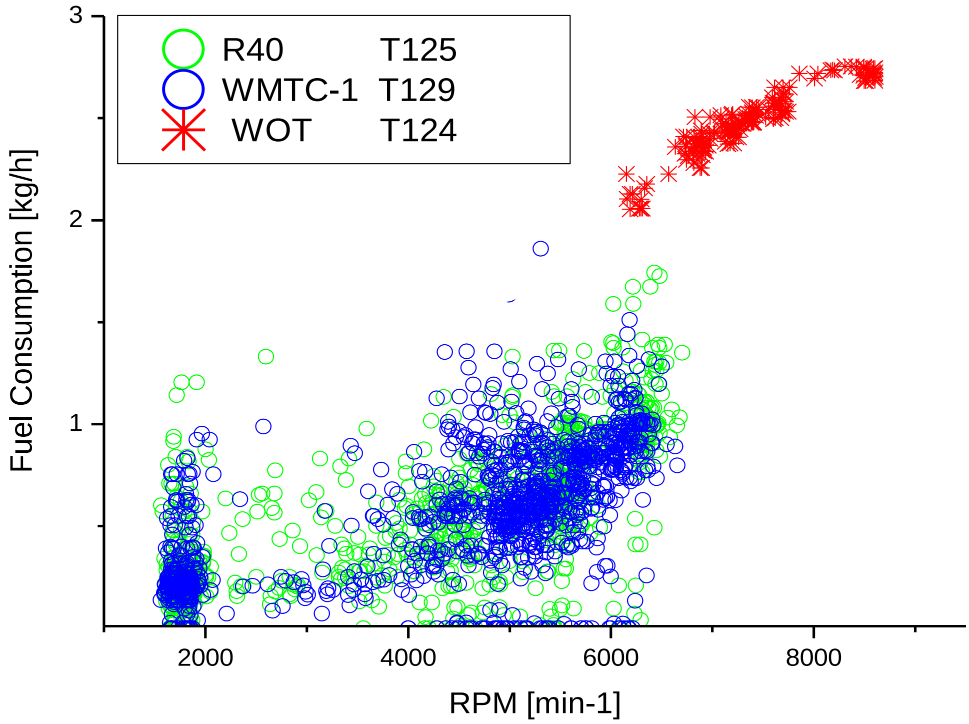


Figure 79. Vehicle 6. Fuel consumption (vertical axis) VS engine speed for different driving cycles.

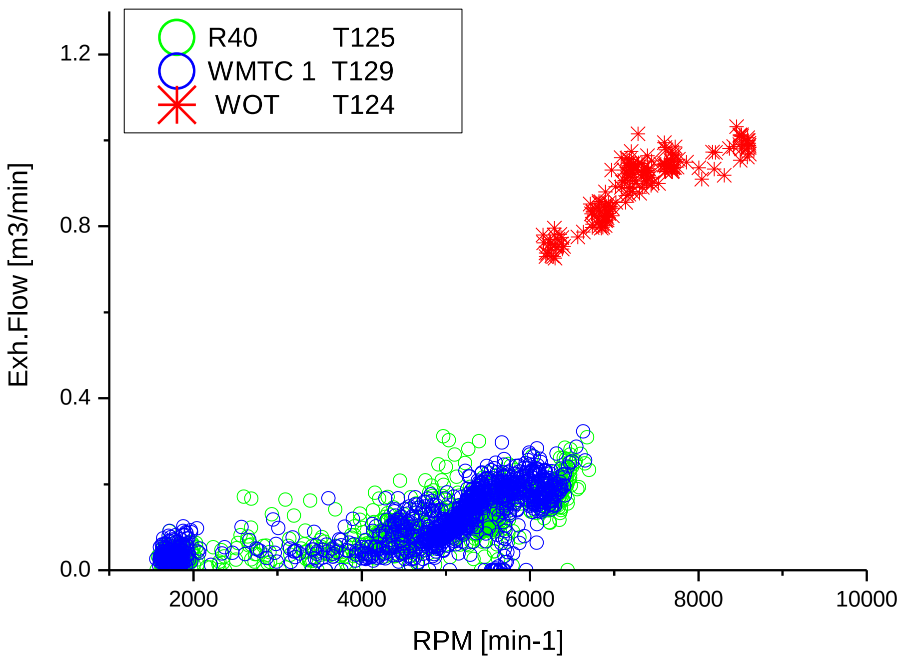


Figure 80. Vehicle 6. Exhaust flow (vertical axis) VS engine speed for different driving cycles.

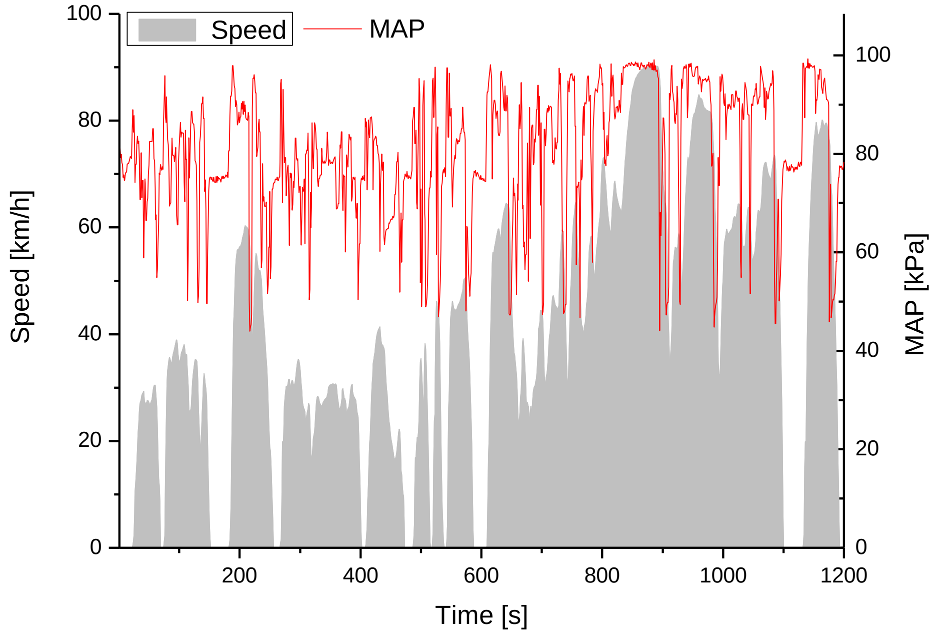


Figure 81. Vehicle 6. Temporal profile of the MAP variable during a WMTC cycle.

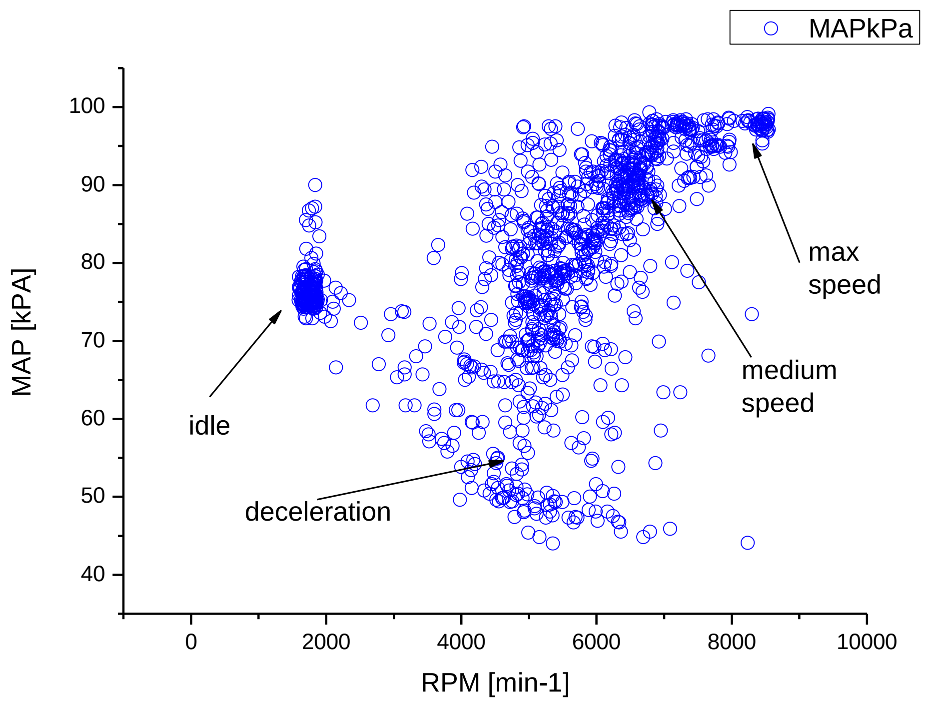


Figure 82. Vehicle 6. MAP (vertical axis) VS engine speed for different driving cycles.

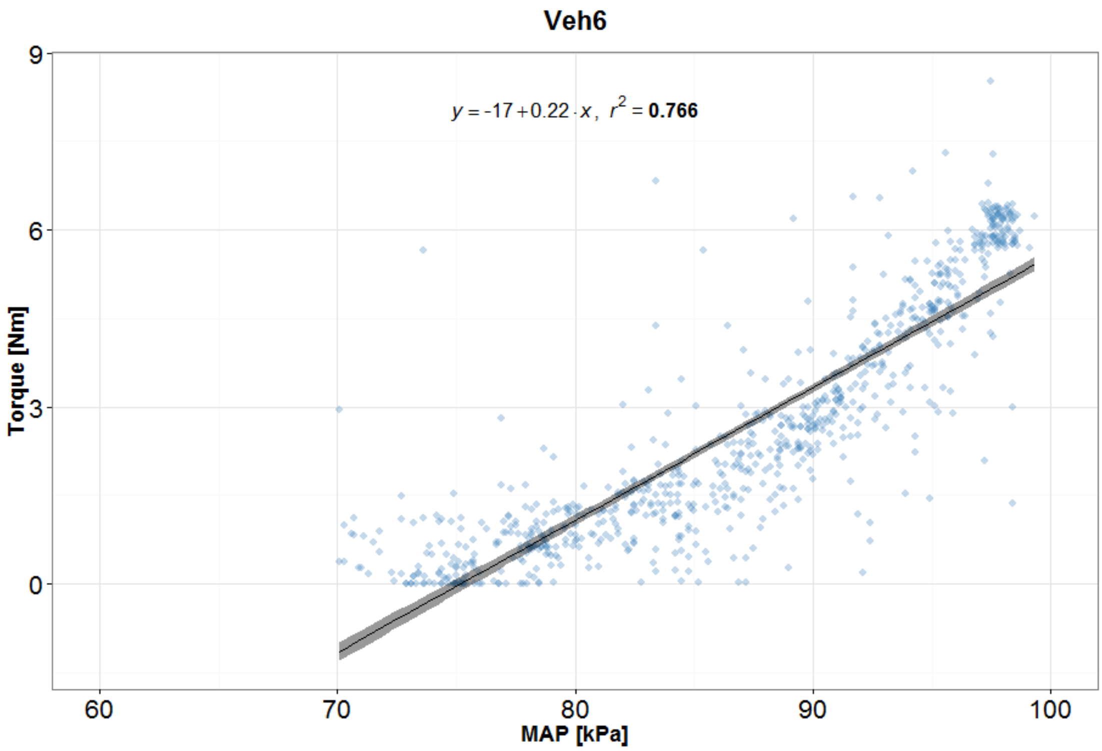


Figure 83. Vehicle 6. Correlation plots of torque VS manifold absolute pressure.

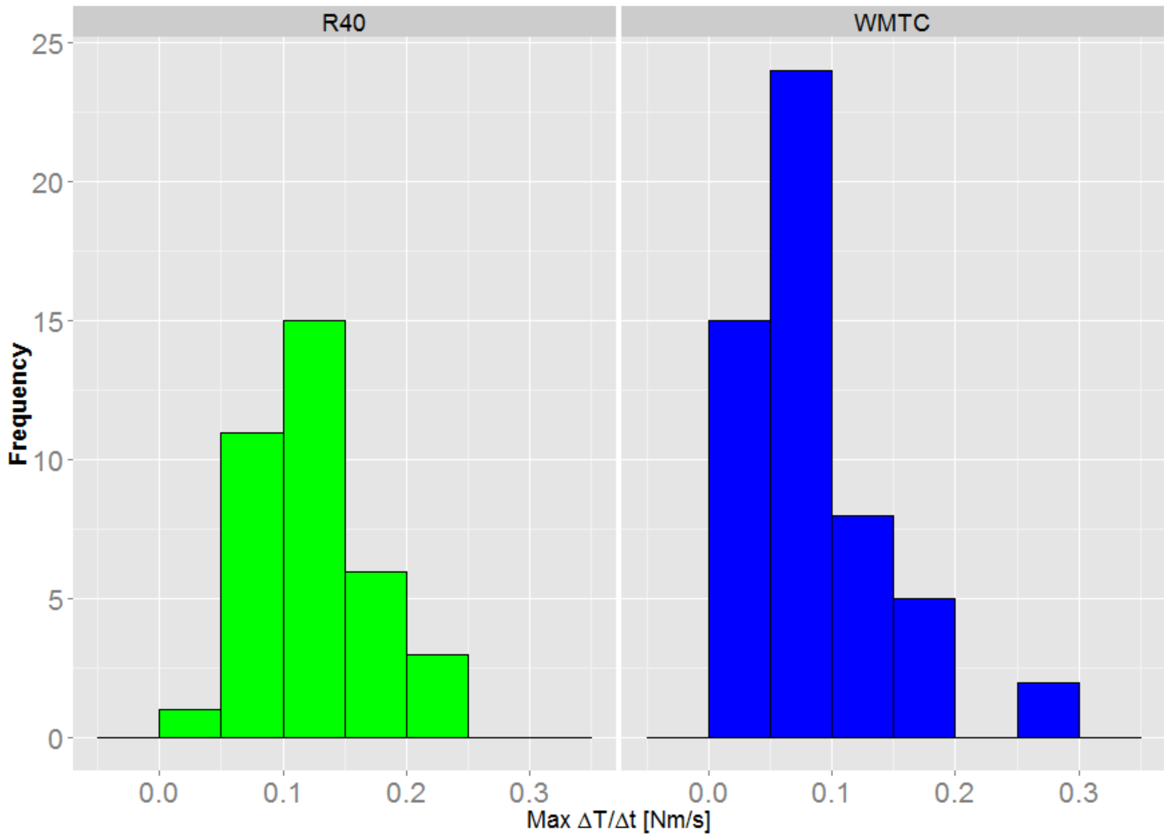


Figure 84. Vehicle 6. *Dynamics* indicator for the assessment of the WMTC.

4.7 Vehicle 7

This is an example of vehicle for which the R40 cycle has a wider coverage of the area below the max power and torque curves. The reason is that WMTC 2-1 has lower speed peaks than the max speed of R40 with EUDC. Nevertheless, the WMTC has lower idle counts and better representation of the area around 50% of load.

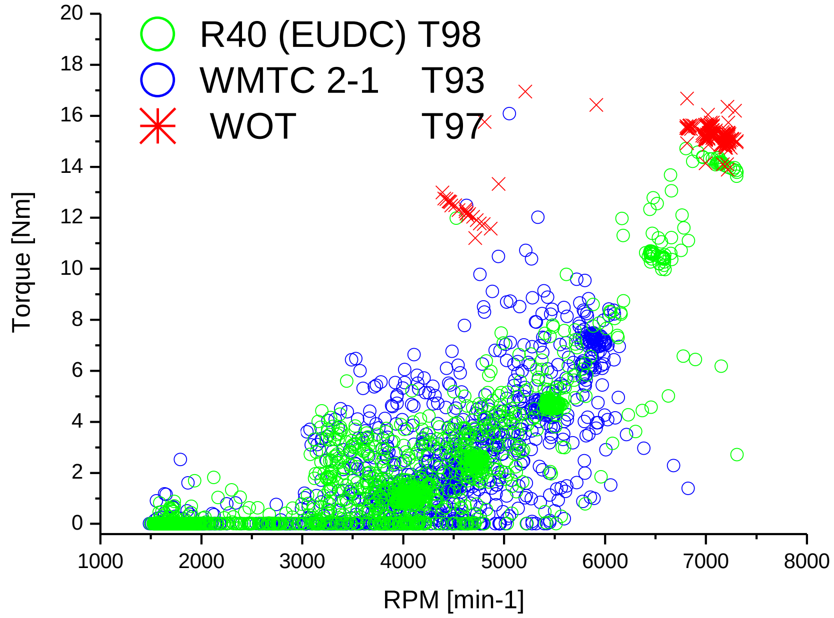


Figure 85. Vehicle 7. Torque (vertical axis) VS engine speed (RPM, min-1) for different driving cycles.

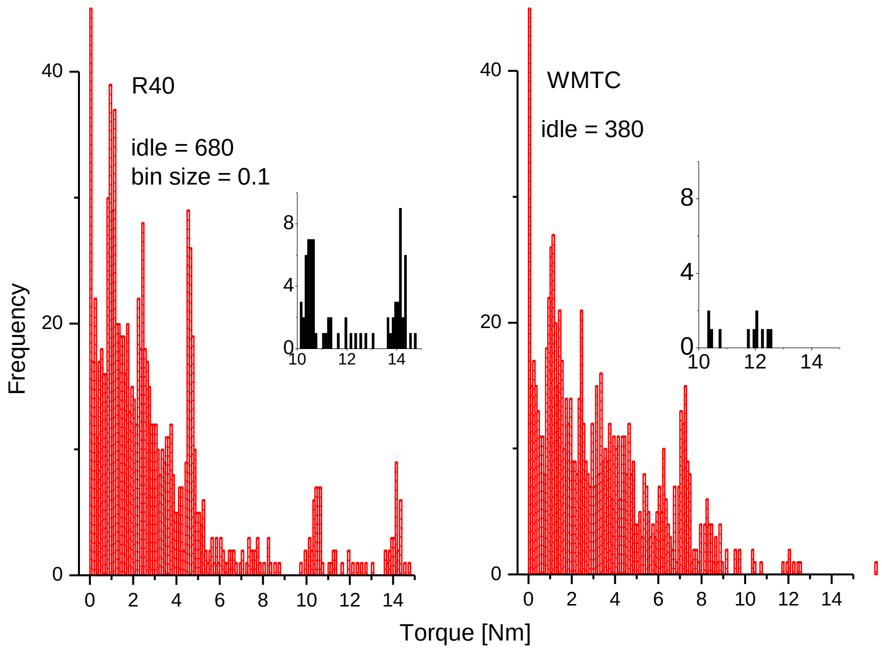


Figure 86. Vehicle 7. Distribution of counts (frequency) for the torque on the horizontal axis.

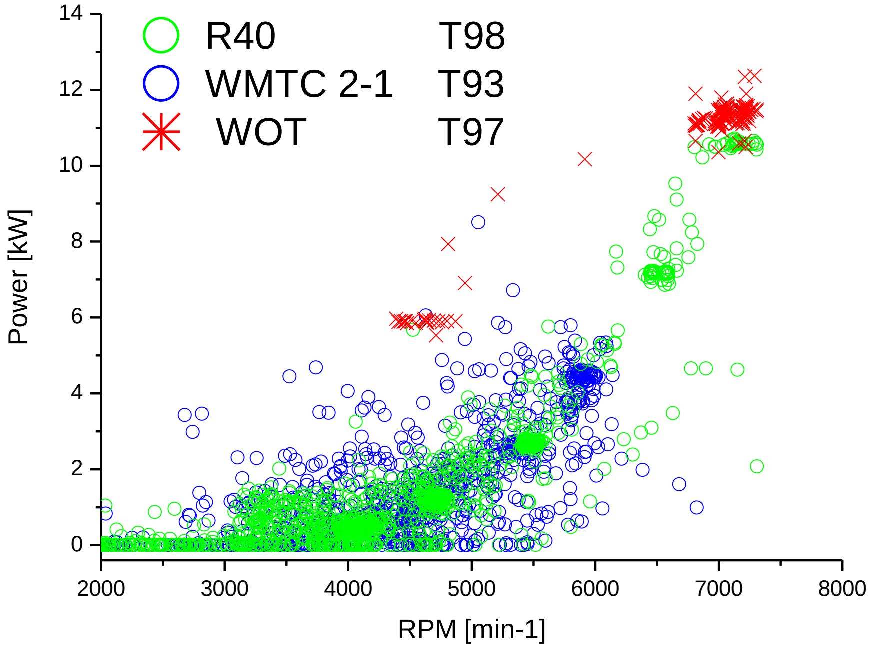


Figure 87. Vehicle 7. Power (vertical axis) VS engine speed for different driving cycles.

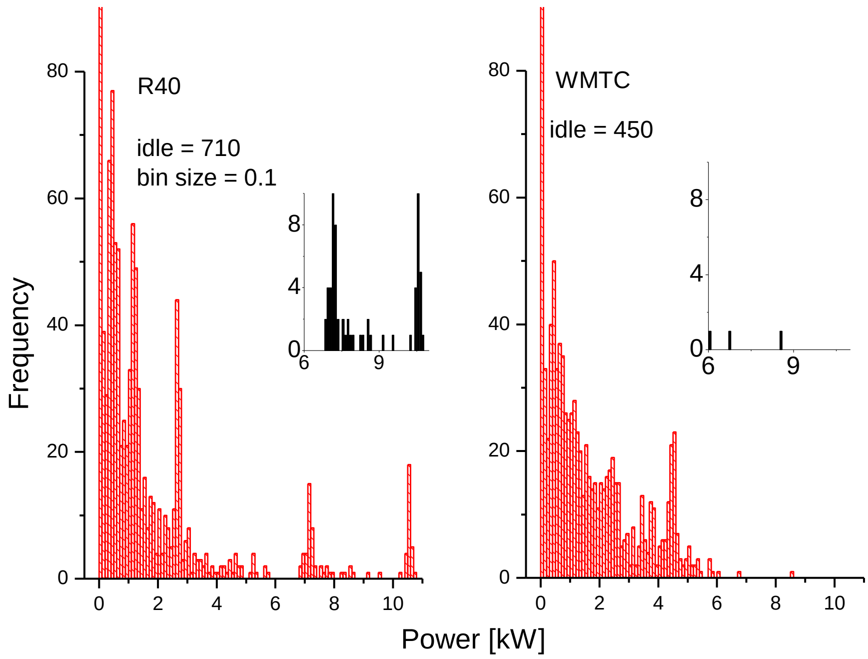


Figure 88. Vehicle 7. Distribution of counts (frequency) for the power on the horizontal axis.

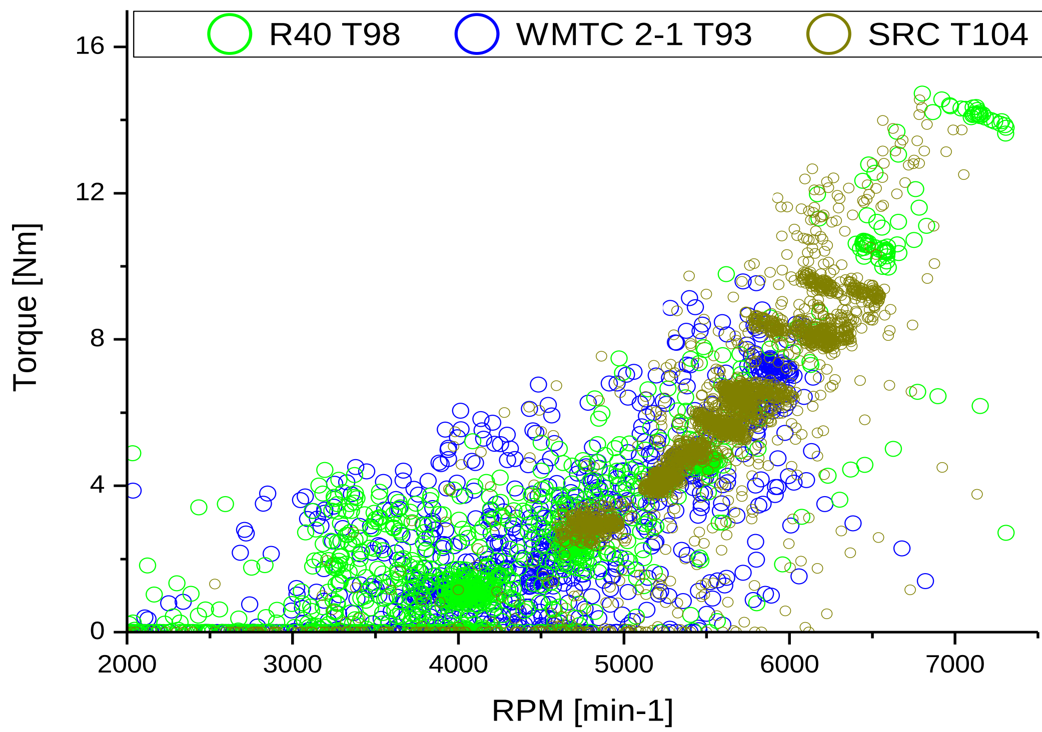


Figure 89. Vehicle 7. Torque (vertical axis) VS engine speed for different driving cycles.

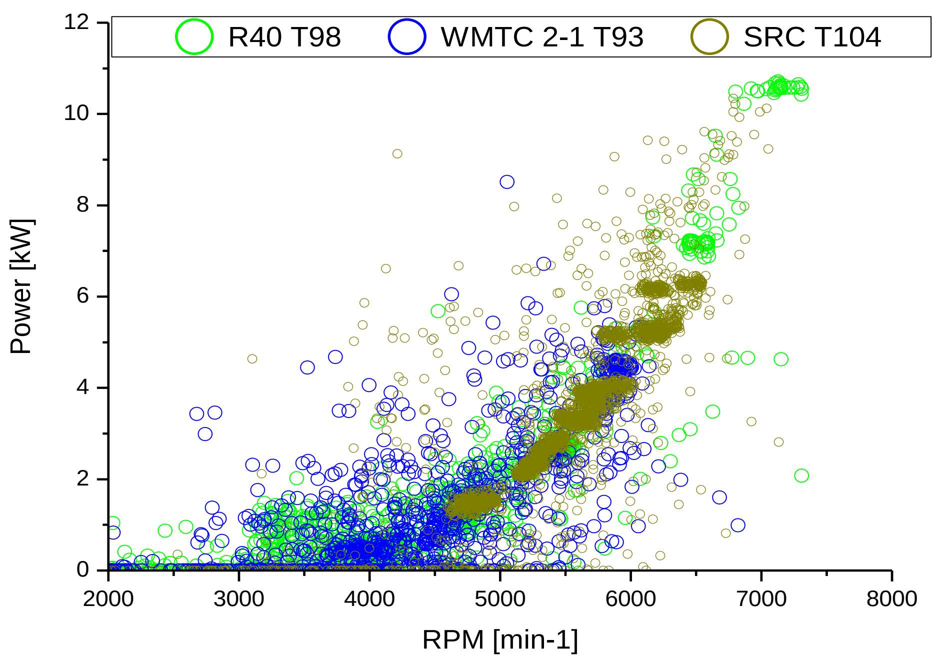


Figure 90. Vehicle 7. Power (vertical axis) VS engine speed for different driving cycles.

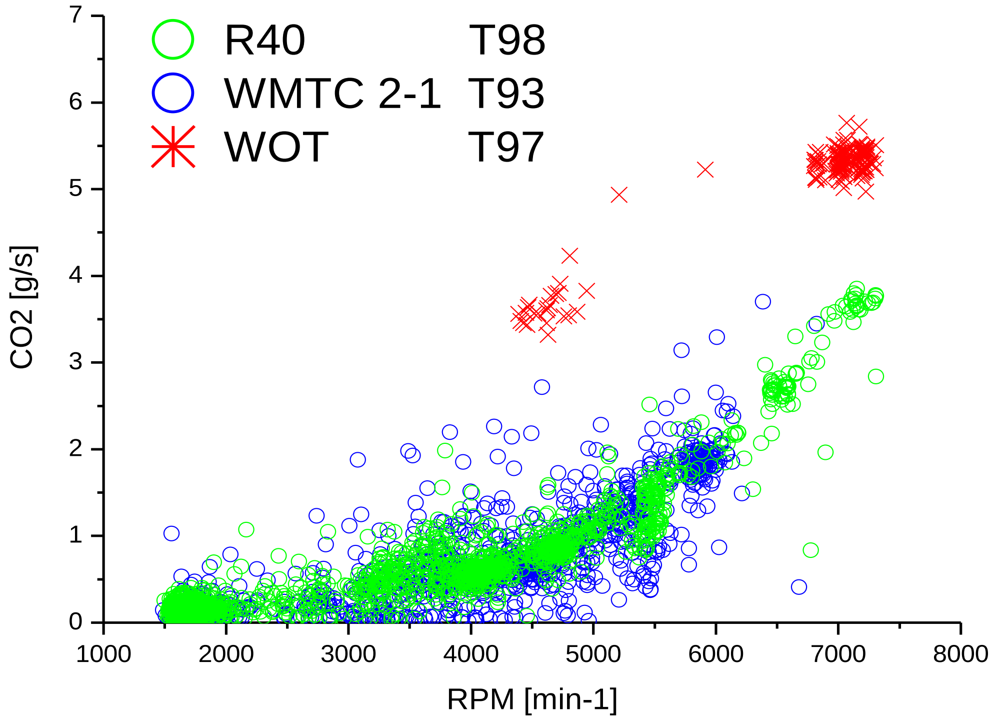


Figure 91. Vehicle 7. CO_2 mass emissions (vertical axis) VS engine speed for different driving cycles.

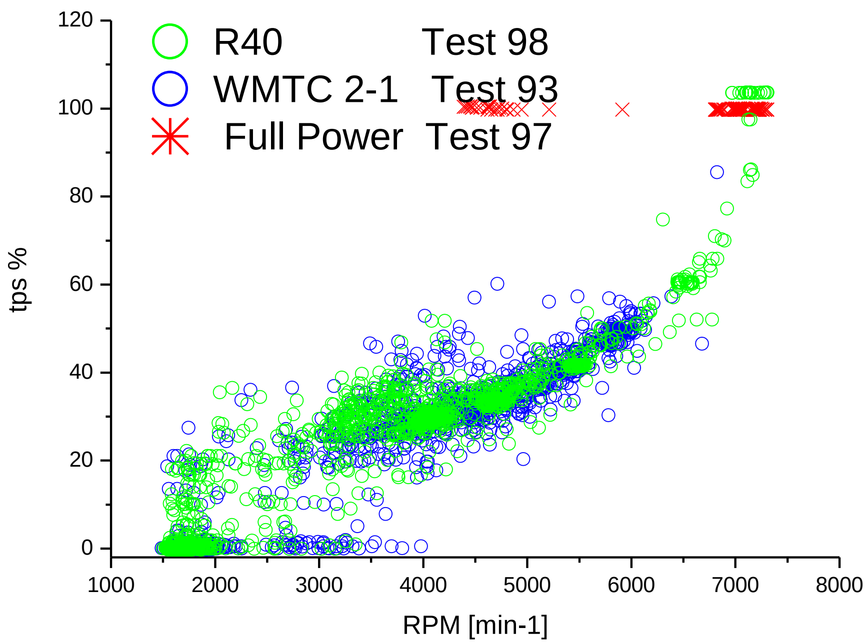


Figure 92. Vehicle 7. Throttle position (vertical axis) VS engine speed for different driving cycles.

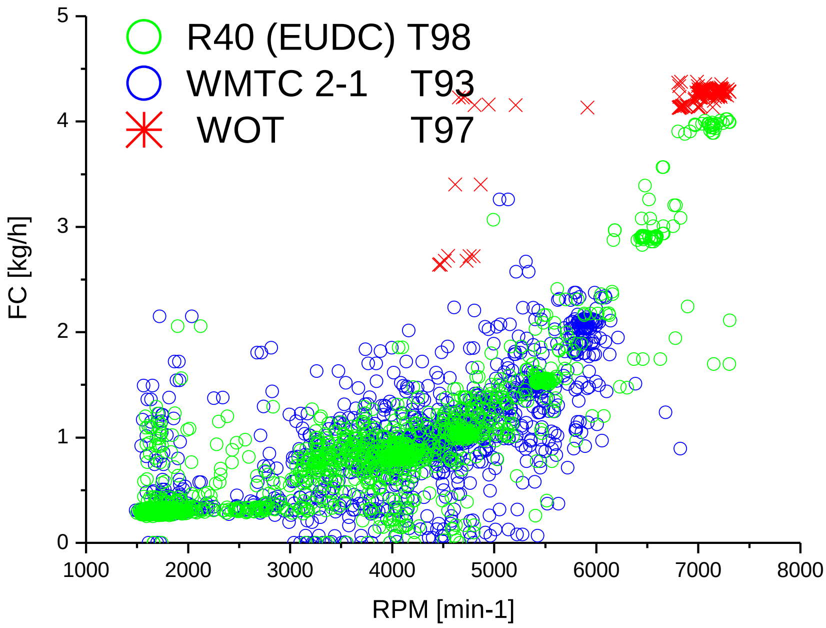


Figure 93. Vehicle 7. Fuel consumption (vertical axis) VS engine speed for different driving cycles.

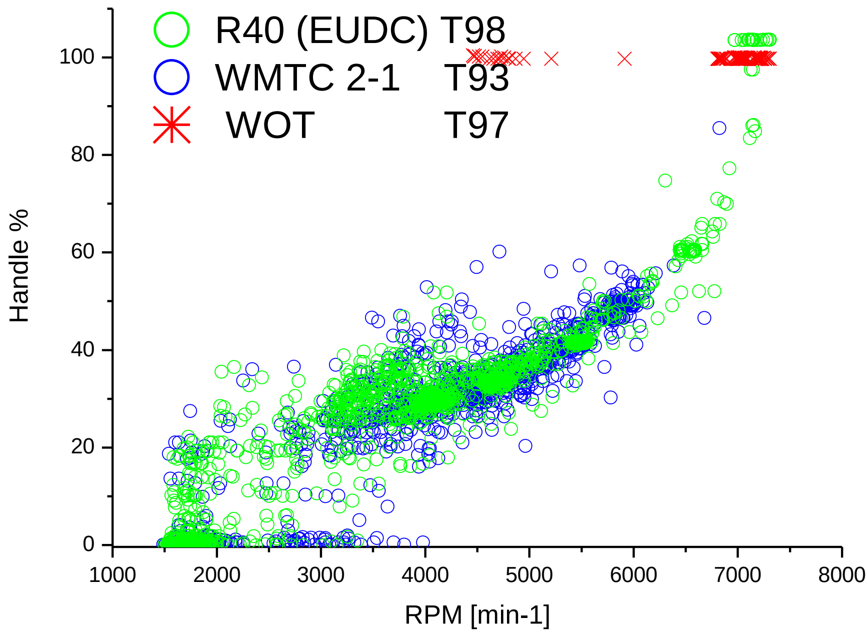


Figure 94. Vehicle 7. Handle position (vertical axis) VS engine speed for different driving cycles.

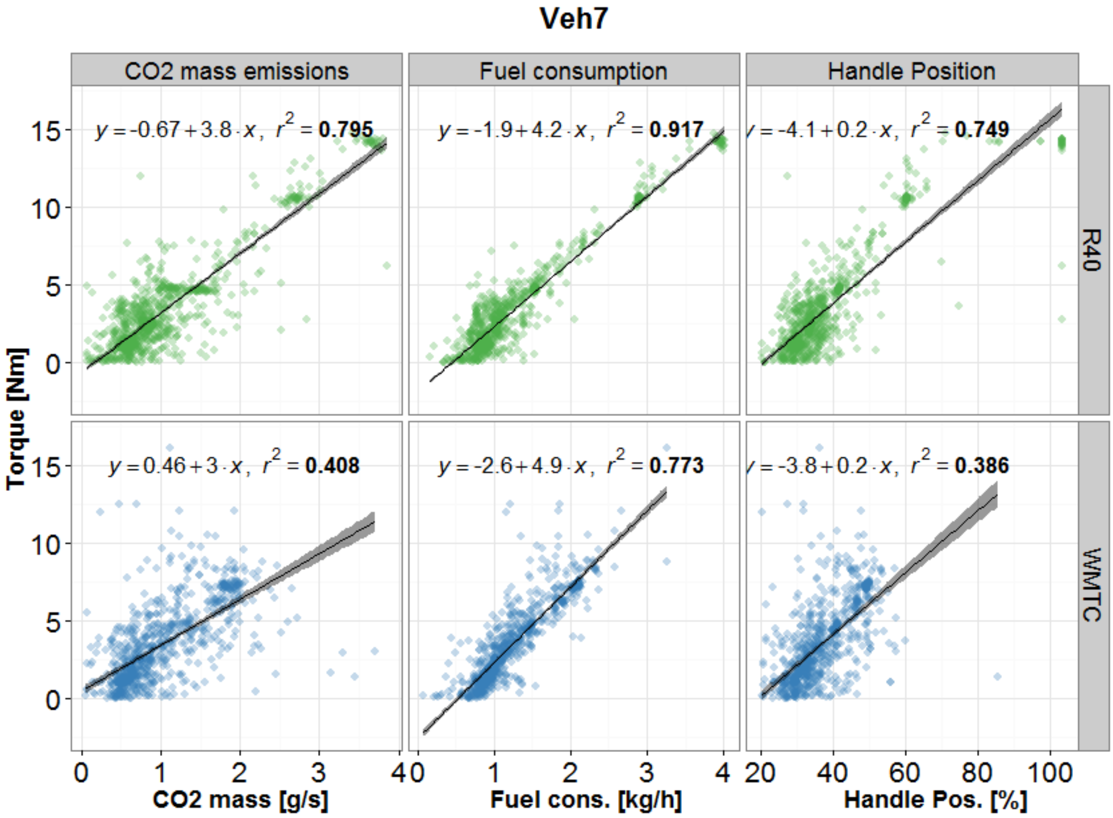


Figure 95. Vehicle 7. Correlation plots of torque VS CO_2 mass concentration, fuel consumption and handle position.

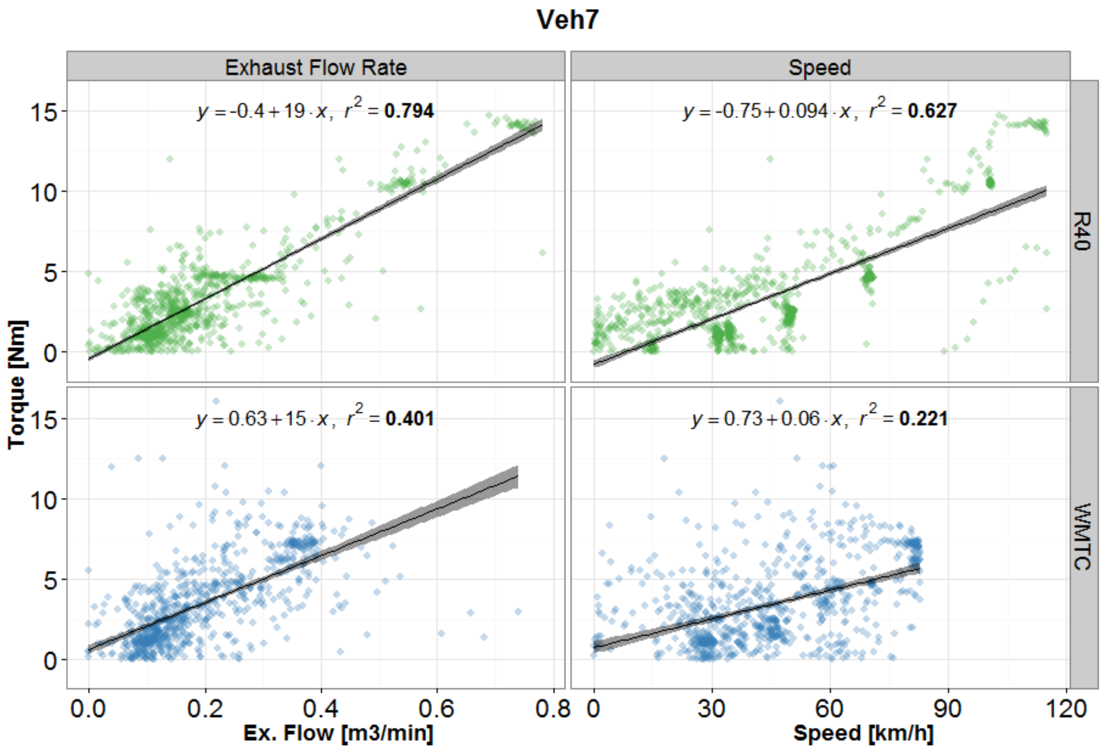


Figure 96. Vehicle 7. Correlation plots of torque VS exhaust flow rate and speed.

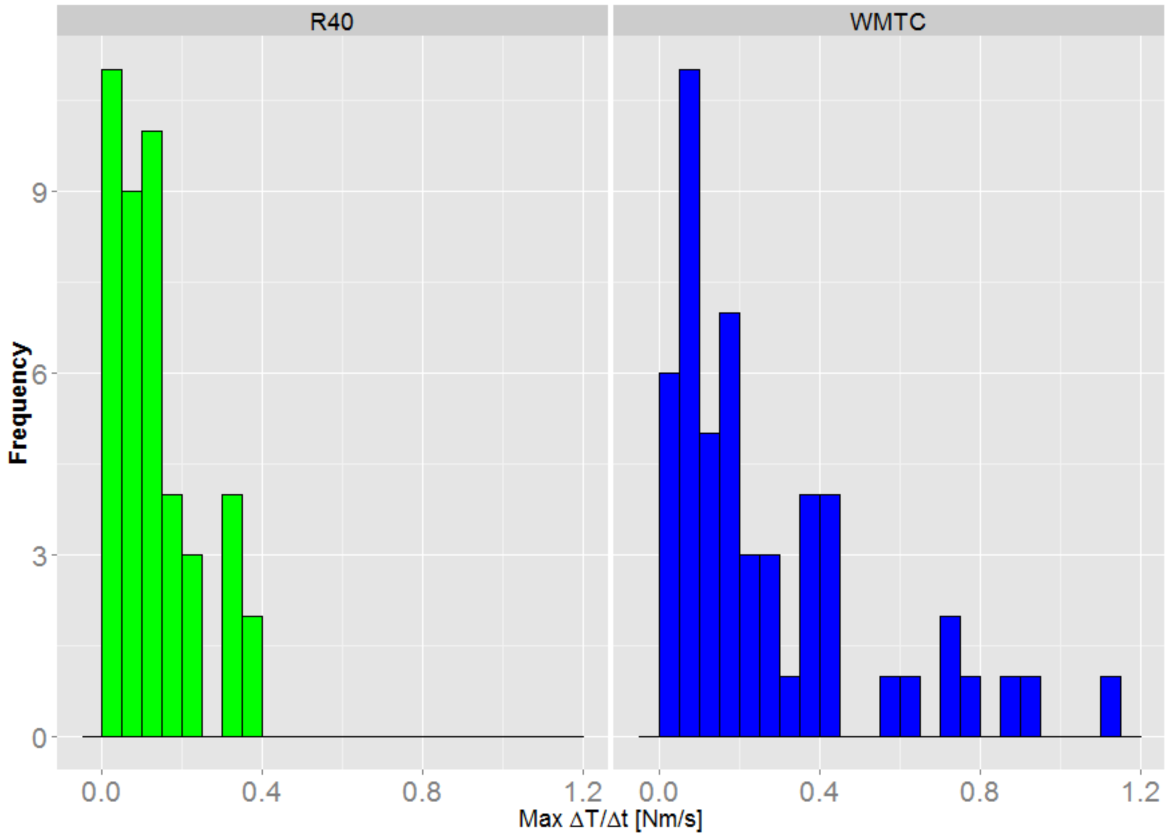


Figure 97. Vehicle 7. *Dynamics* indicator for the assessment of the WMTC.

4.8 Vehicle 8

The WMTC cycle better cover the area below the max Torque curve with respect to R40.

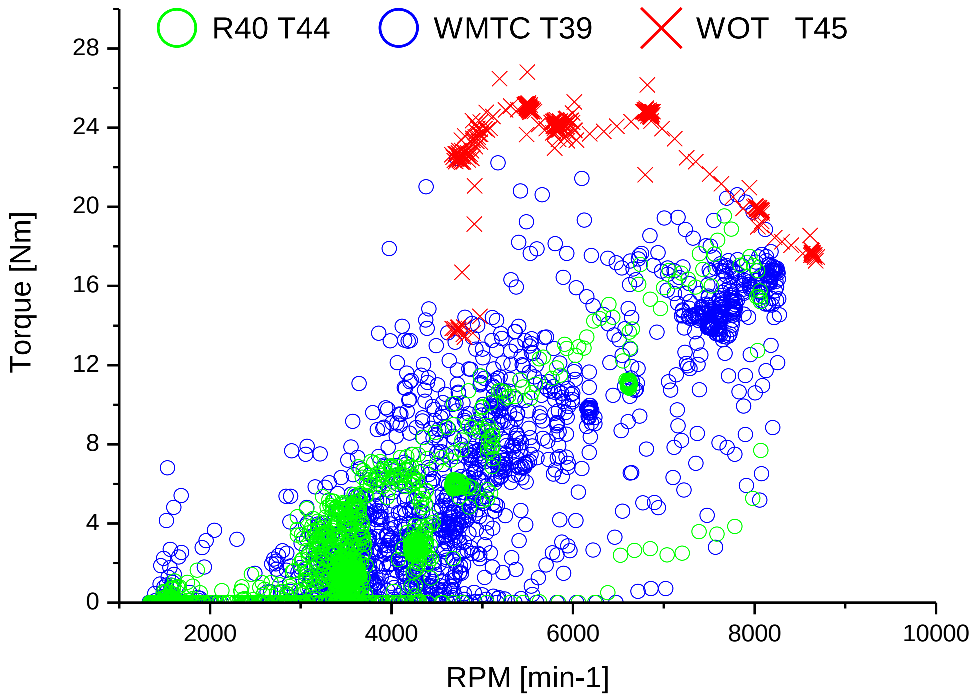


Figure 98. Vehicle 8. Torque (vertical axis) VS engine speed (RPM, min-1) for different driving cycles.

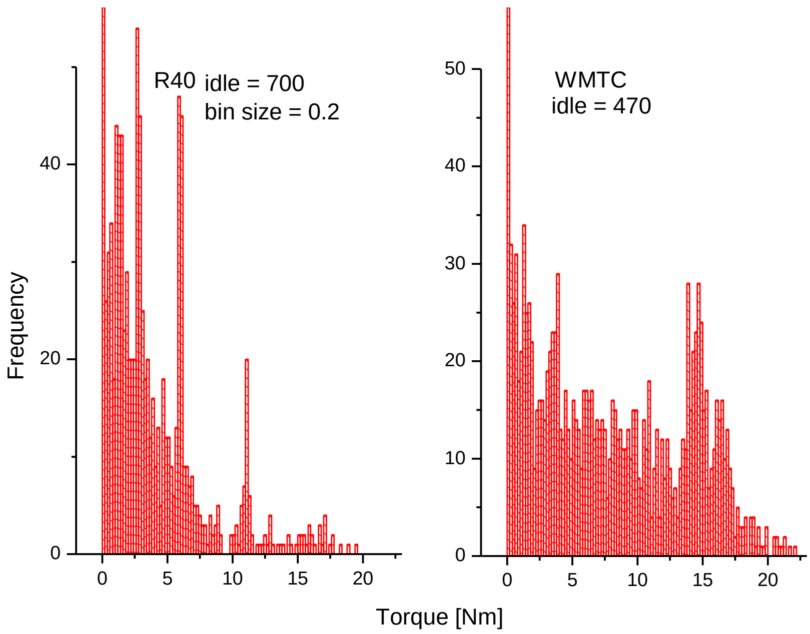


Figure 99. Vehicle 8. Distribution of counts (frequency) for the torque on the horizontal axis.

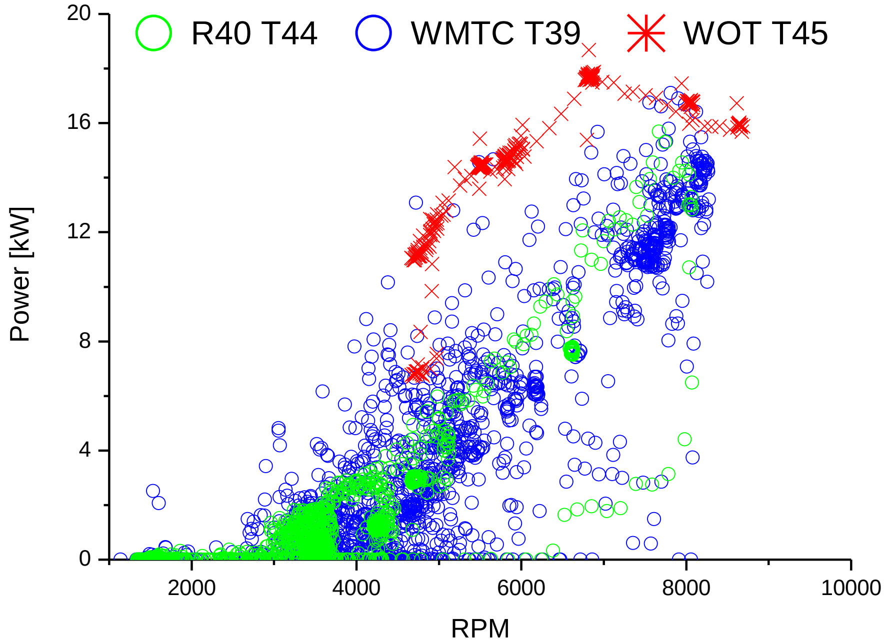


Figure 100. Vehicle 8. Power (vertical axis) VS engine speed for different driving cycles.

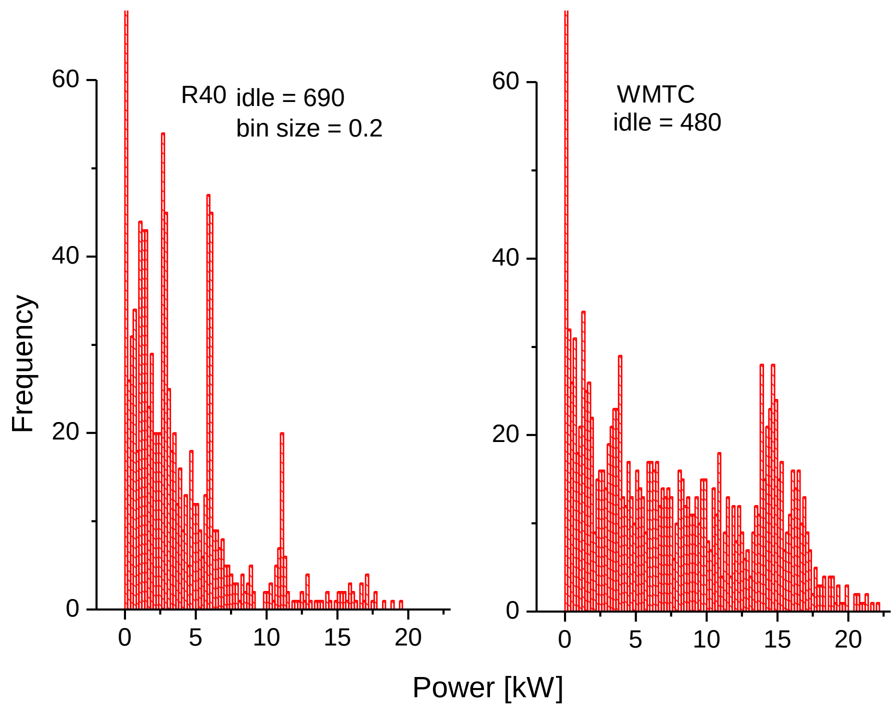


Figure 101. Vehicle 8. Distribution of counts (frequency) for the power on the horizontal axis.

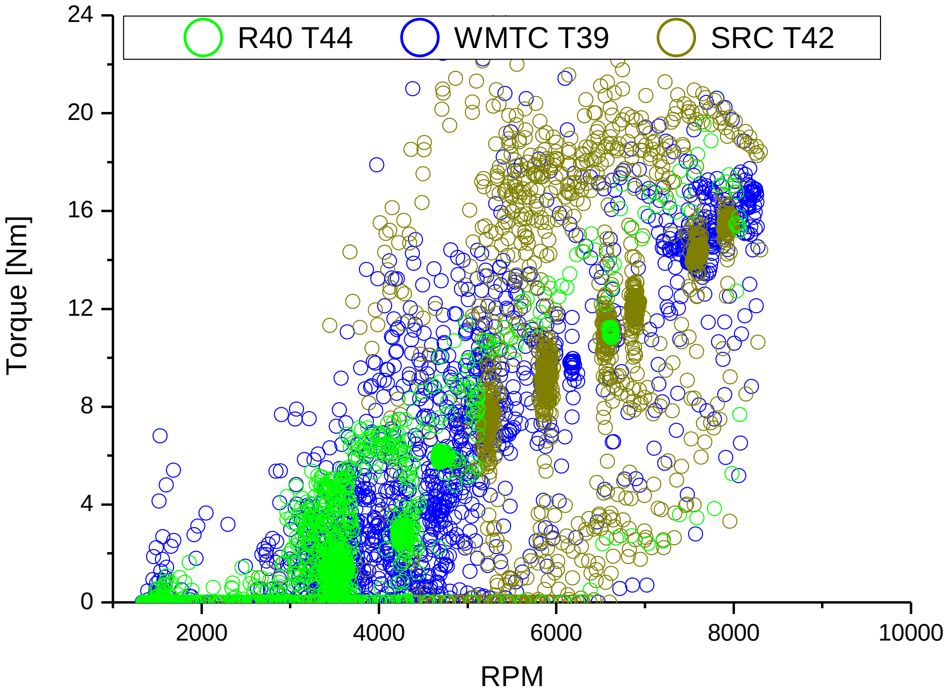


Figure 102. Vehicle 8. Torque (vertical axis) VS engine speed for different driving cycles including the SRC-Le.

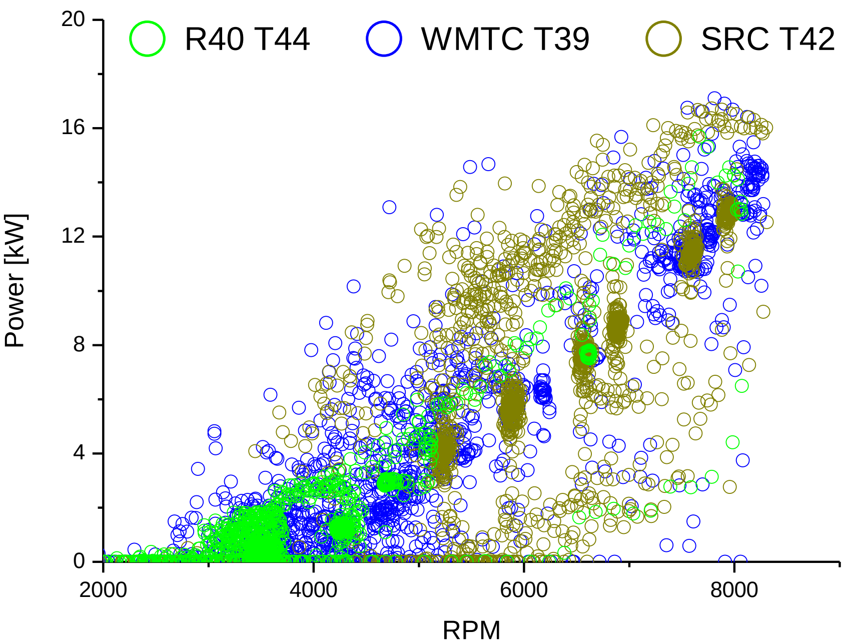


Figure 103. Vehicle 8. Power (vertical axis) VS engine speed for different driving cycles including the SRC-Le.

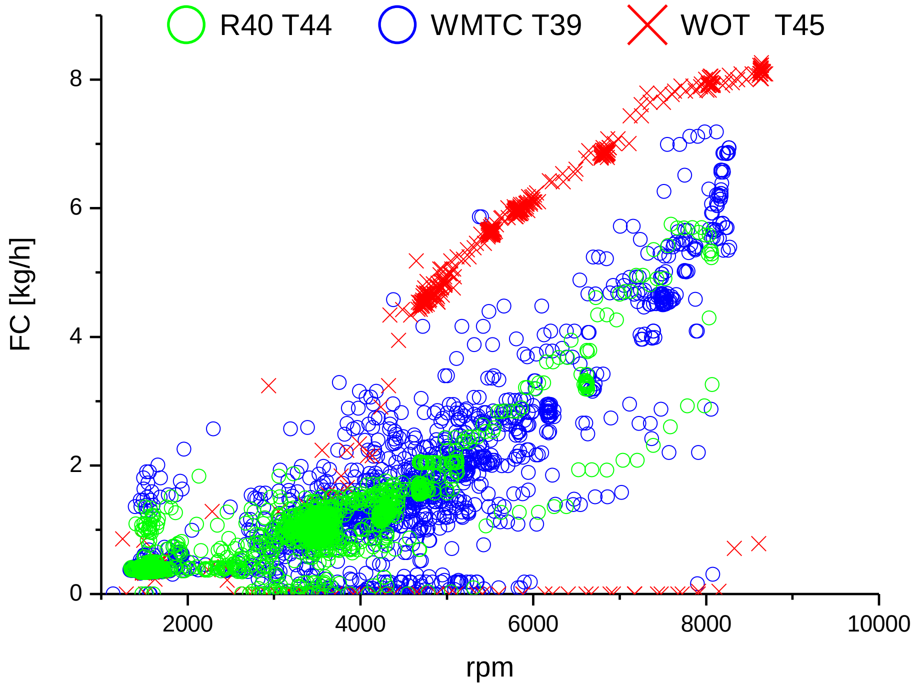


Figure 104. Vehicle 8. Fuel consumption (vertical axis) VS engine speed for different driving cycles.

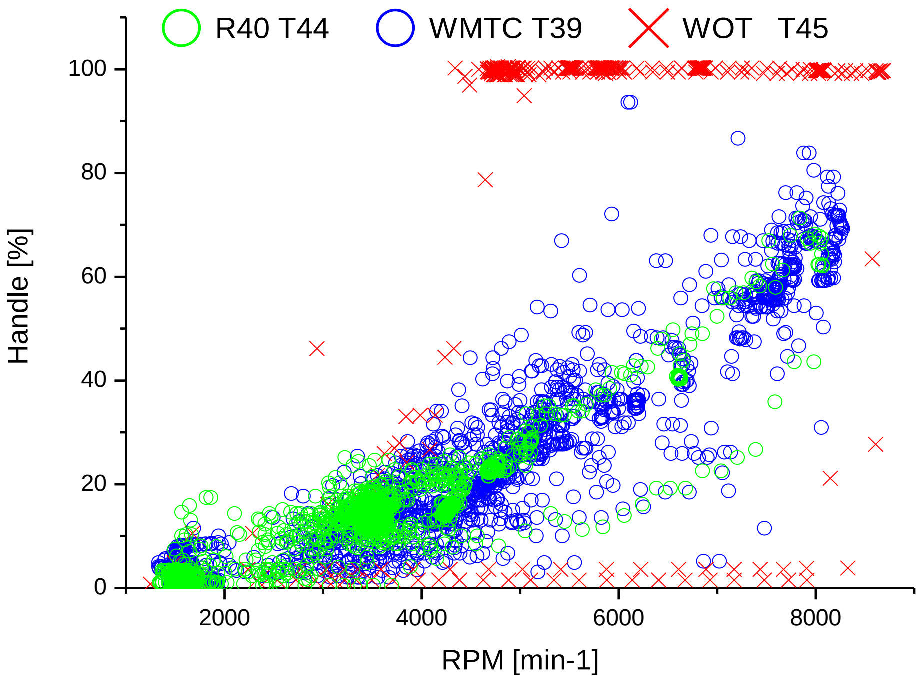


Figure 105. Vehicle 8. Handle position (vertical axis) VS engine speed for different driving cycles.

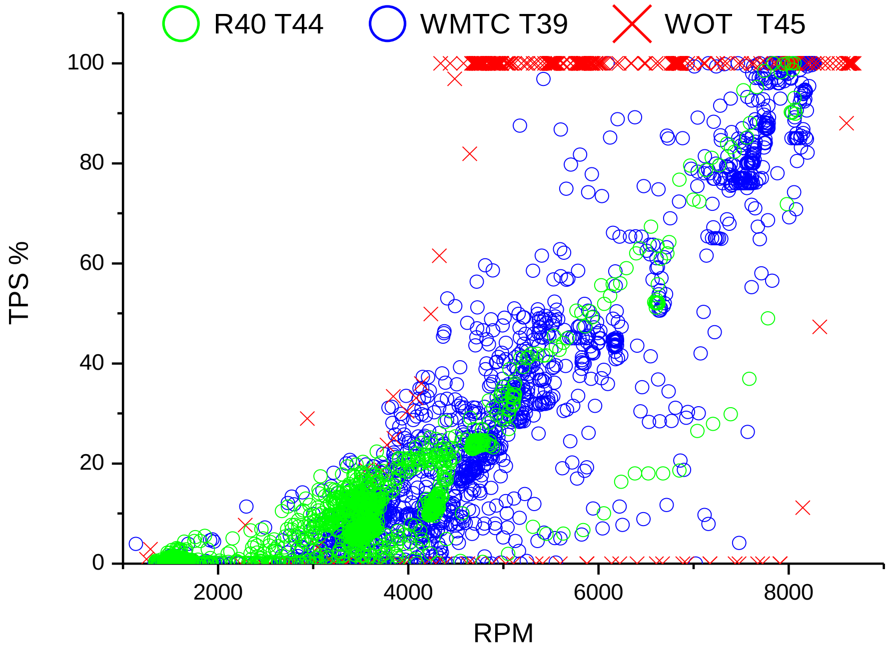


Figure 106. Vehicle 8. Throttle position (vertical axis) VS engine speed for different driving cycles.

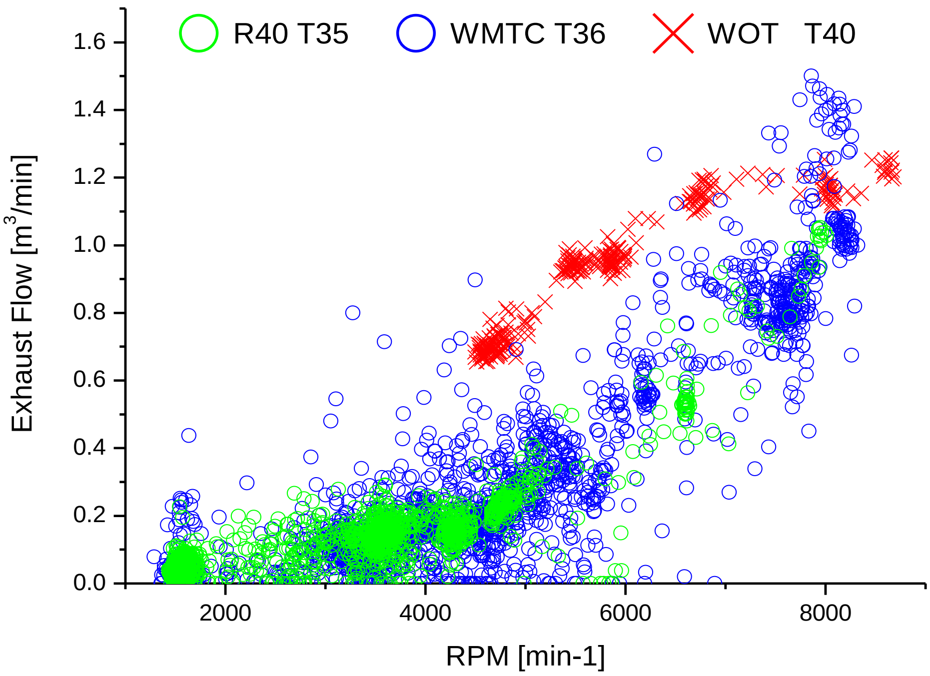


Figure 107. Vehicle 8. Exhaust flow (vertical axis) VS engine speed for different driving cycles.

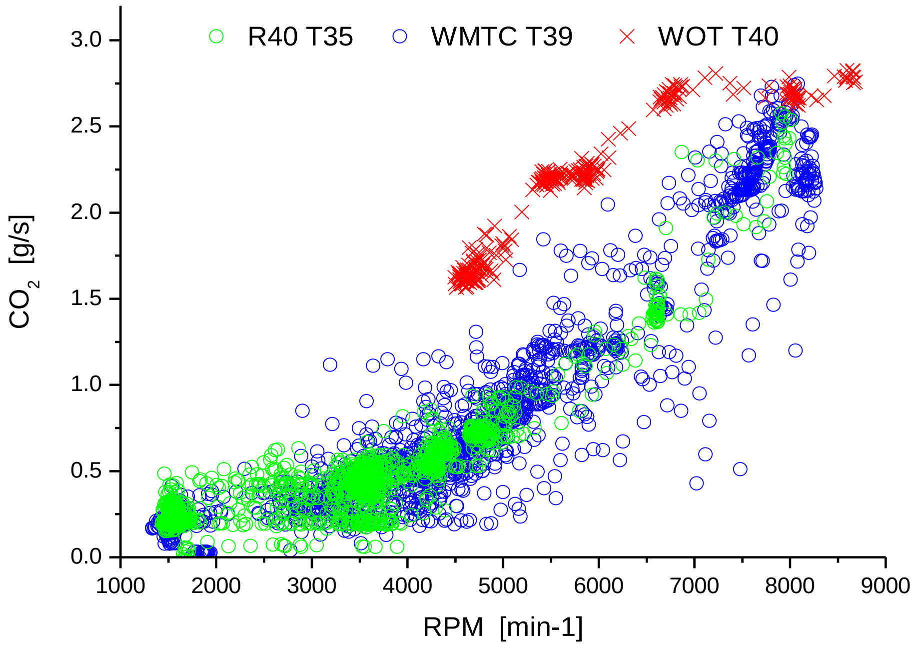


Figure 108. Vehicle 8. CO_2 mass emissions (vertical axis) VS engine speed for different driving cycles.

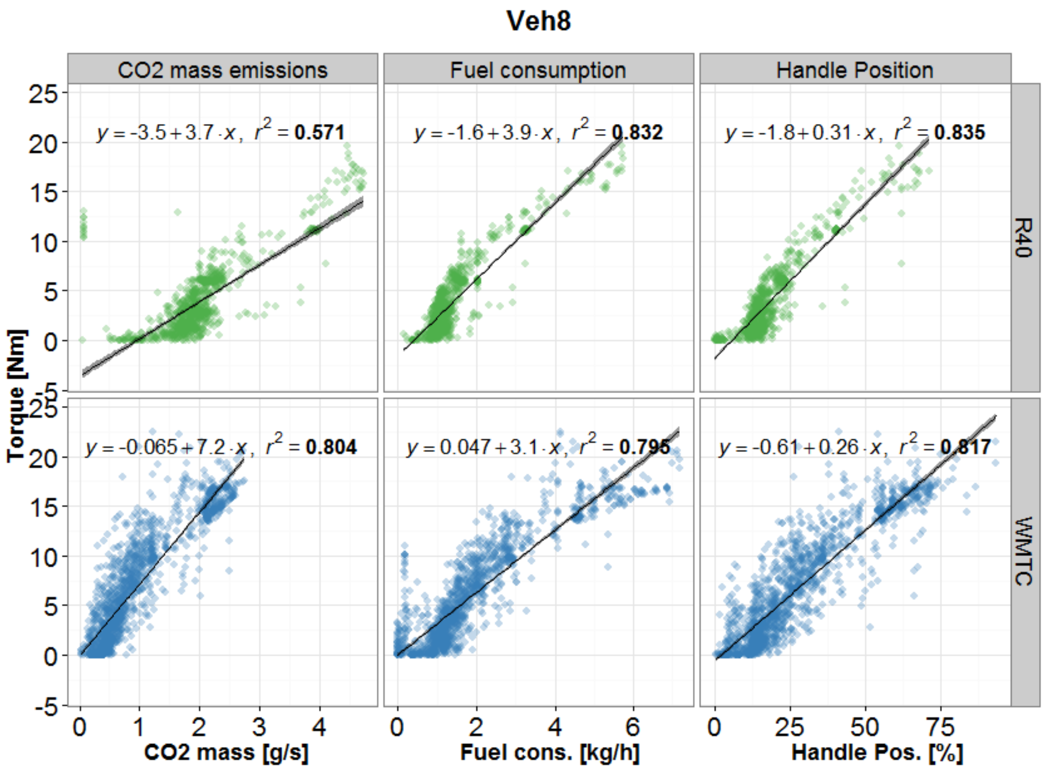


Figure 109. Vehicle 8. Correlation plots of torque VS CO_2 mass concentration, fuel consumption and handle position.

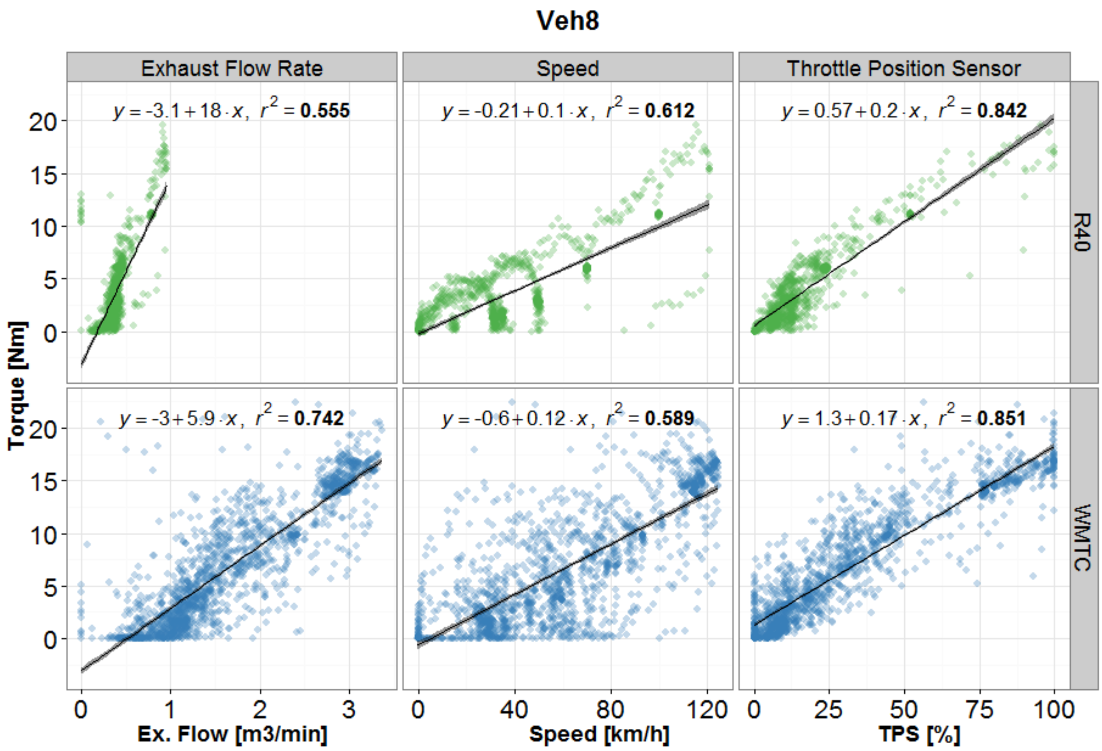


Figure 110. Vehicle 8. Correlation plots of torque VS exhaust flow rate, speed and throttle position.

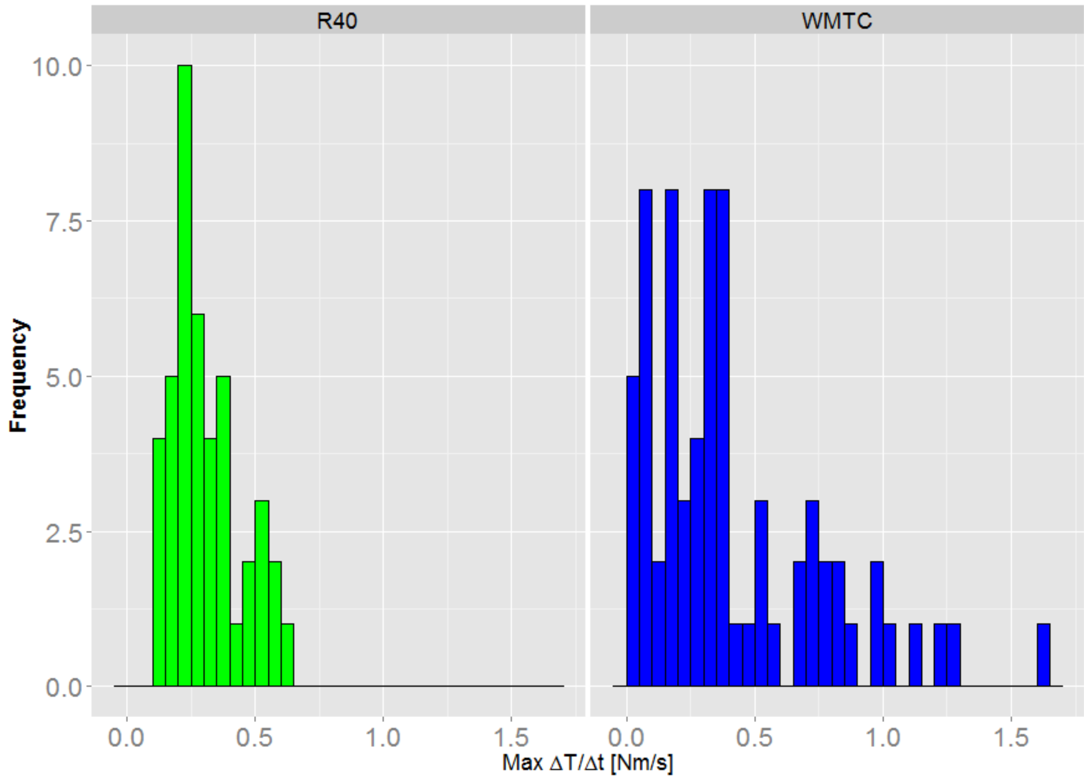


Figure 111. Vehicle 8. *Dynamics* indicator for the assessment of the WMTC.

4.9 Vehicle 9

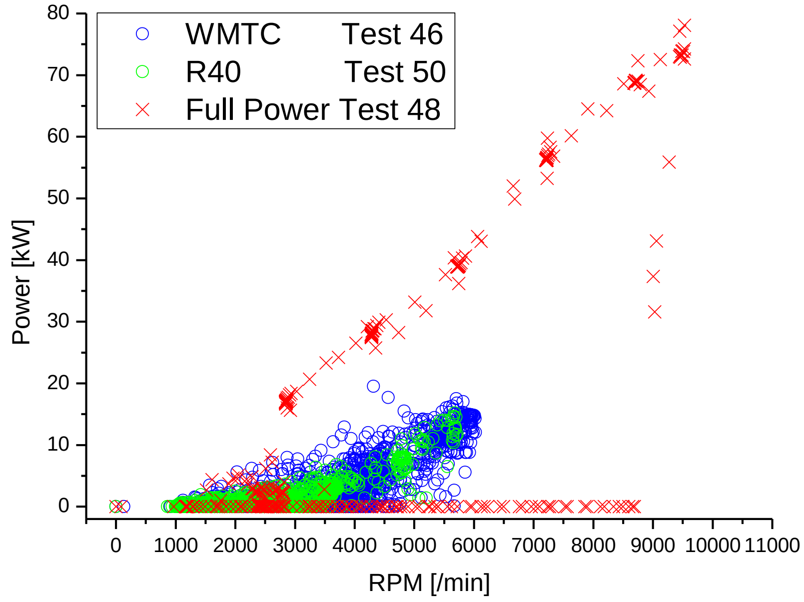


Figure 112. Vehicle 9. Power (vertical axis) VS engine speed (RPM, min-1) for different driving cycles.

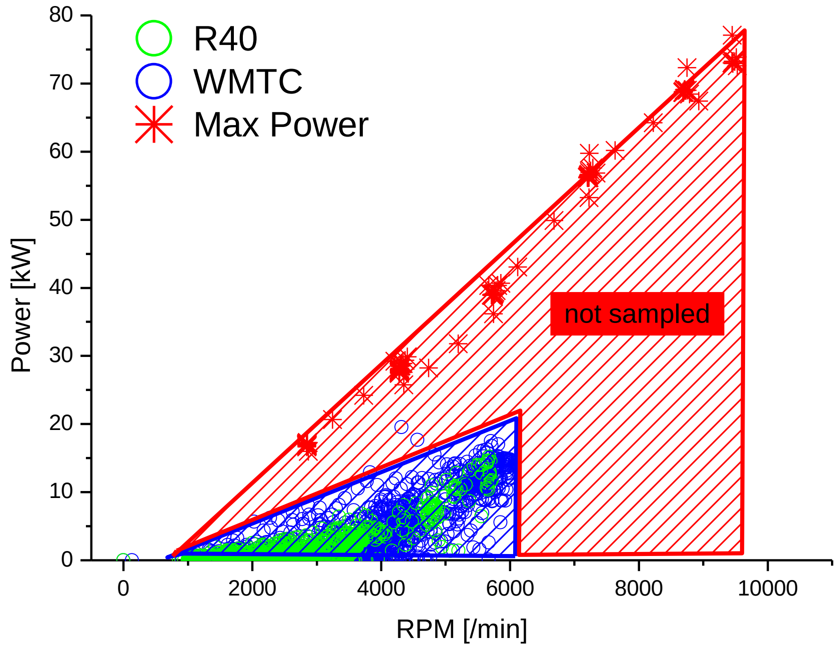


Figure 113. Vehicle 9. Power (vertical axis) VS engine speed for different driving cycles.

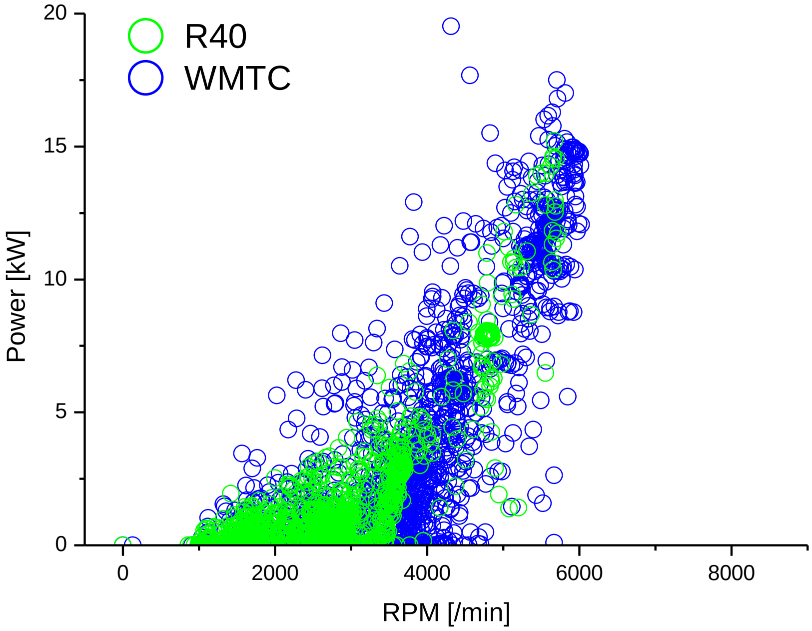


Figure 114. Vehicle 9. Power (vertical axis) VS engine speed for different driving cycles.

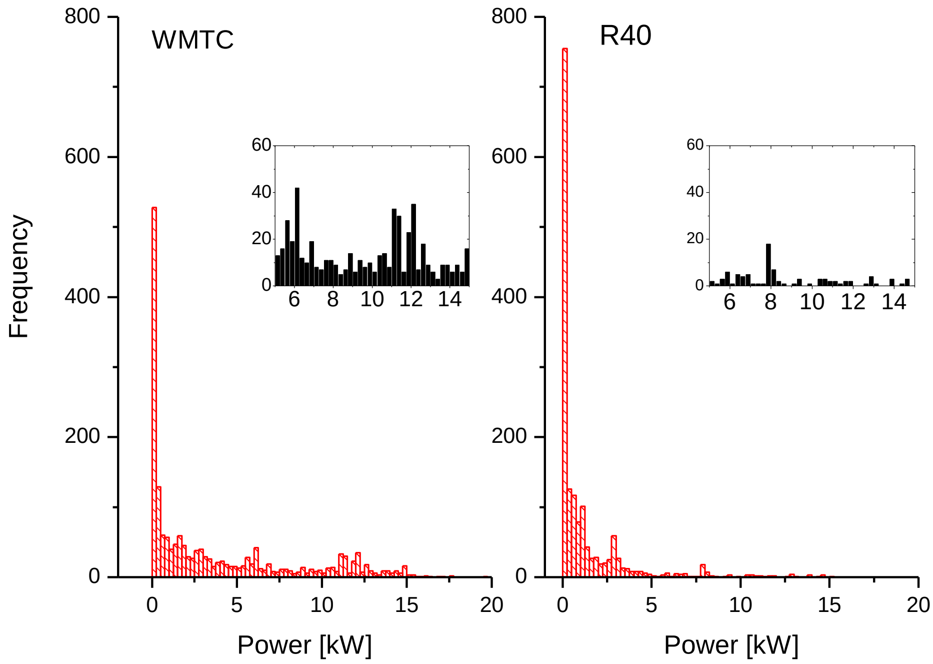


Figure 115. Vehicle 9. Distribution of counts (frequency) for the power on the horizontal axis.

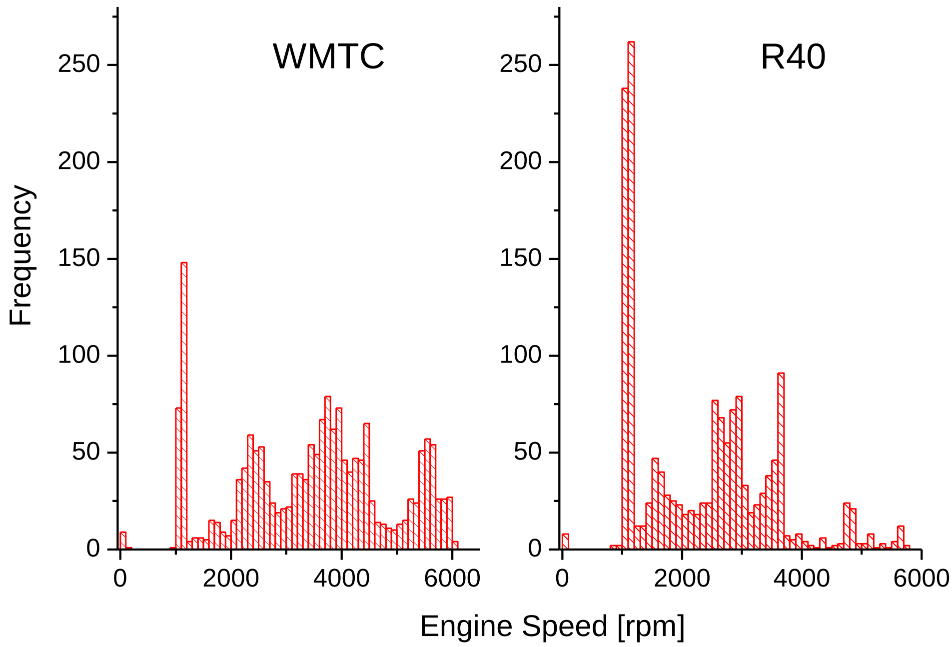


Figure 116. Vehicle 9. Distribution of counts (frequency) for the engine speed on the horizontal axis.

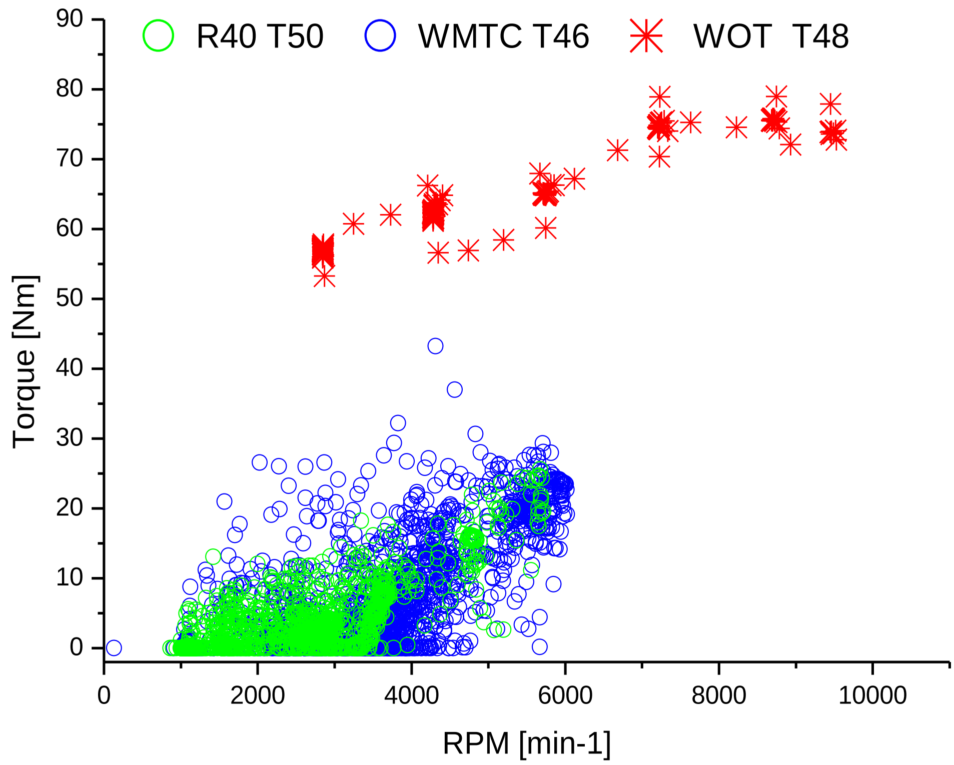


Figure 117. Vehicle 9. Torque VS engine speed for different driving cycles.

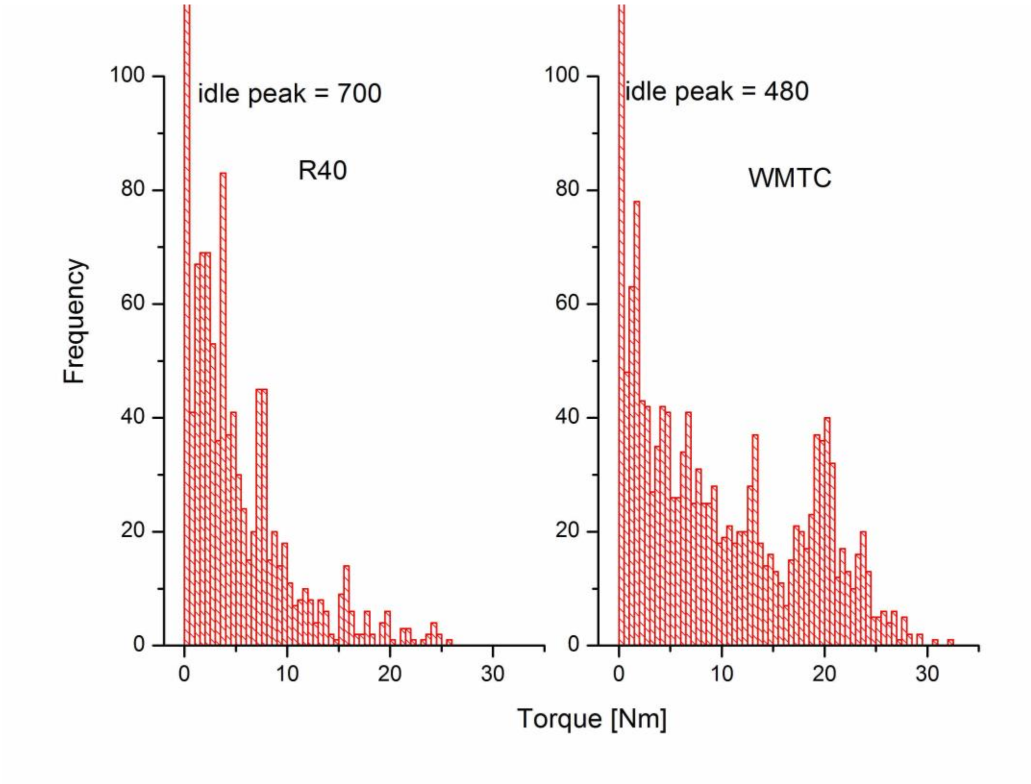


Figure 118. Vehicle 9. Distribution of counts (frequency) for the torque on the horizontal axis.

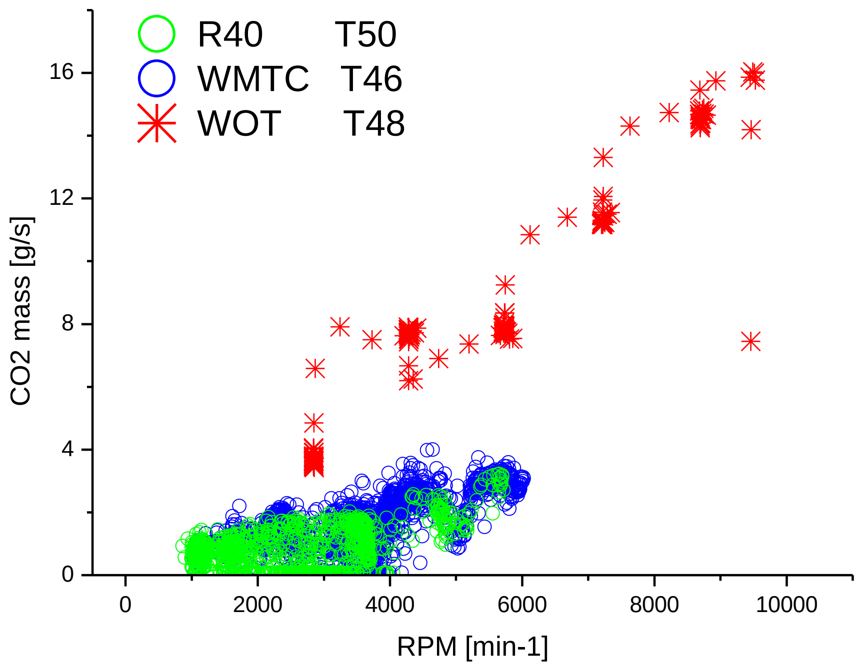


Figure 119. Vehicle 9. CO_2 mass emissions (vertical axis) VS engine speed for different driving cycles.

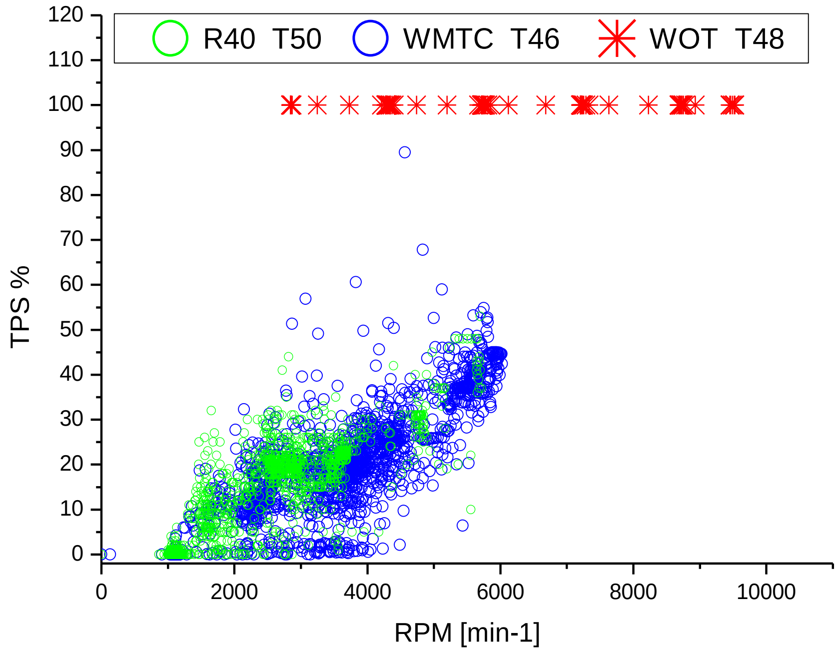


Figure 120. Vehicle 9. Throttle position (vertical axis) VS engine speed for different driving cycles.

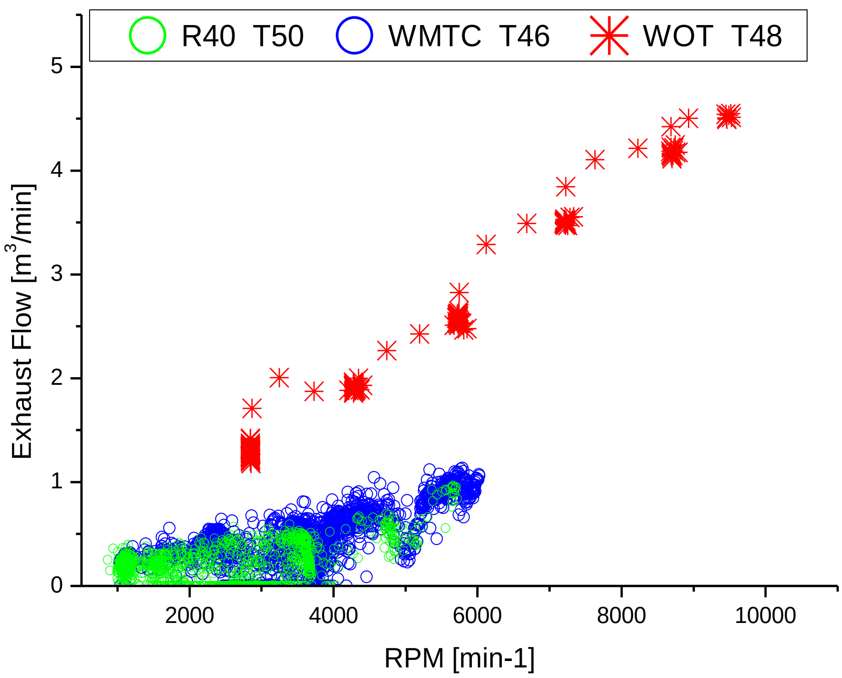


Figure 121. Vehicle 9. Exhaust flow (vertical axis) VS engine speed for different driving cycles.

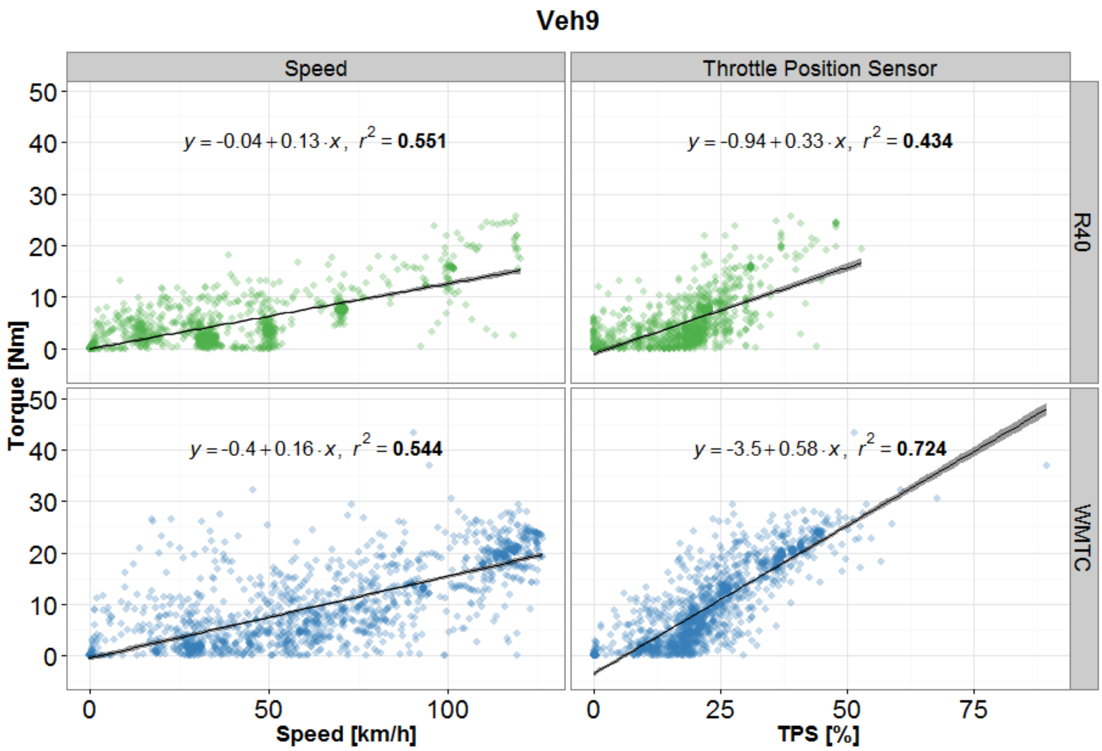


Figure 122. Vehicle 9. Correlation plots of torque VS speed and throttle position.

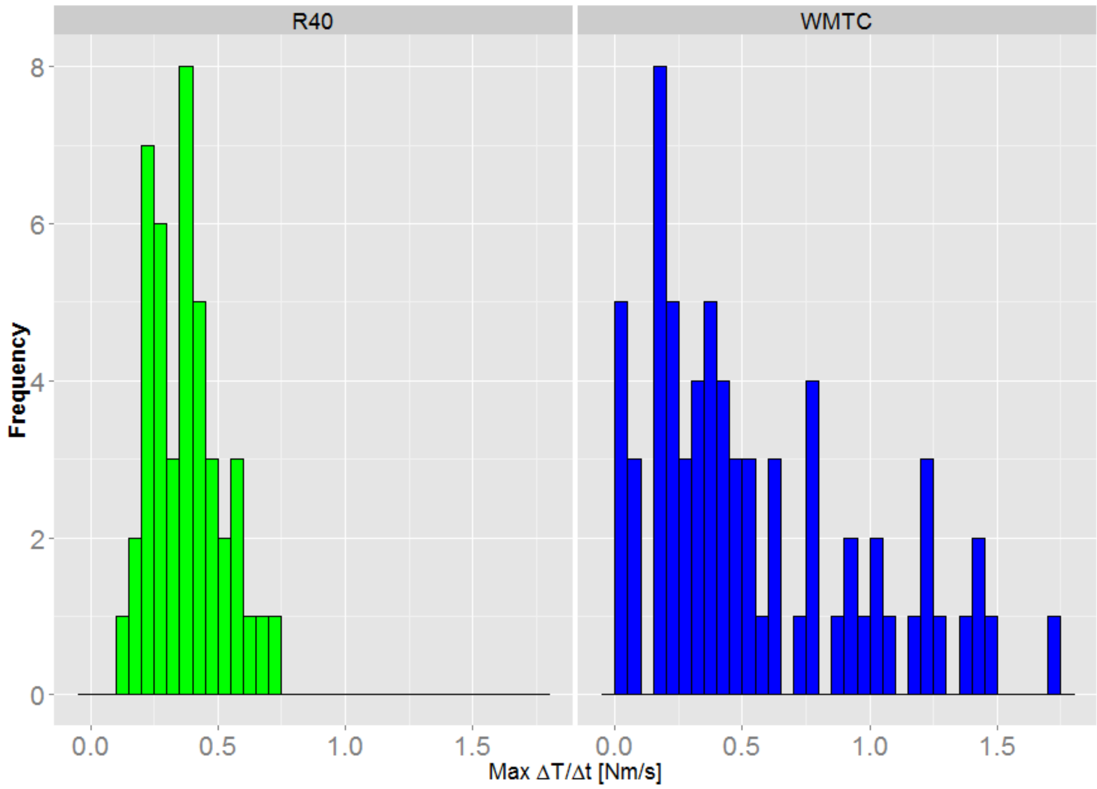


Figure 123. Vehicle 9. *Dynamics* indicator for the assessment of the WMTC.

4.10 Vehicle 10

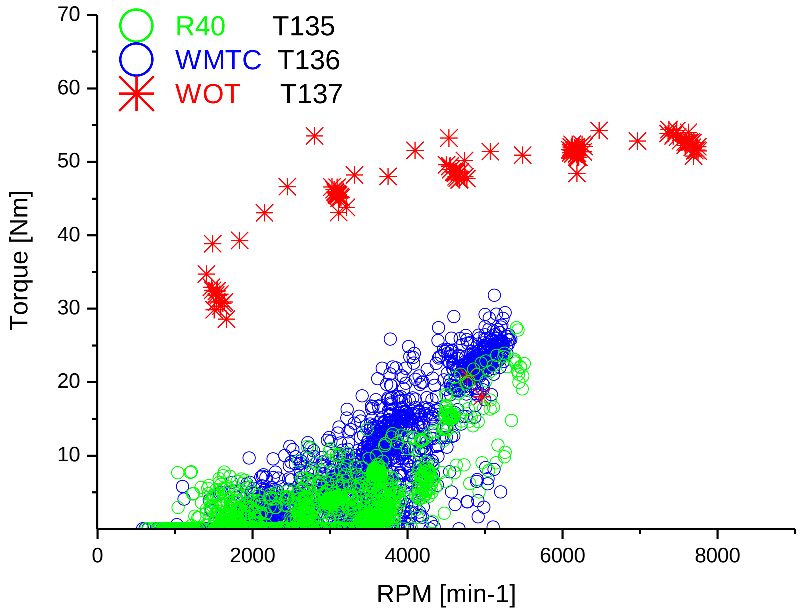


Figure 124. Vehicle 10. Torque (vertical axis) VS engine speed (RPM, min-1) for different driving cycles.

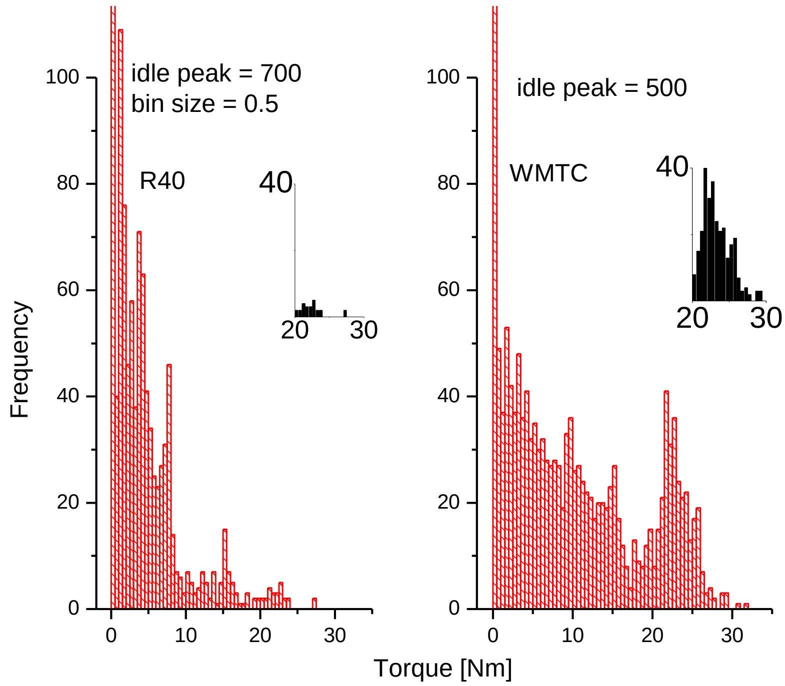


Figure 125. Vehicle 10. Distribution of counts (frequency) for the torque on the horizontal axis.

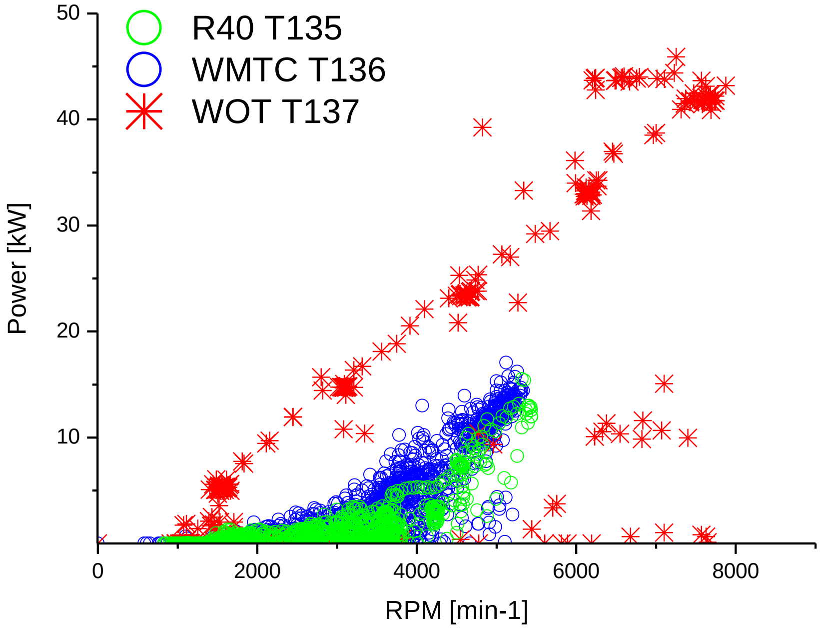


Figure 126. Vehicle 10. Power (vertical axis) VS engine speed for different driving cycles.

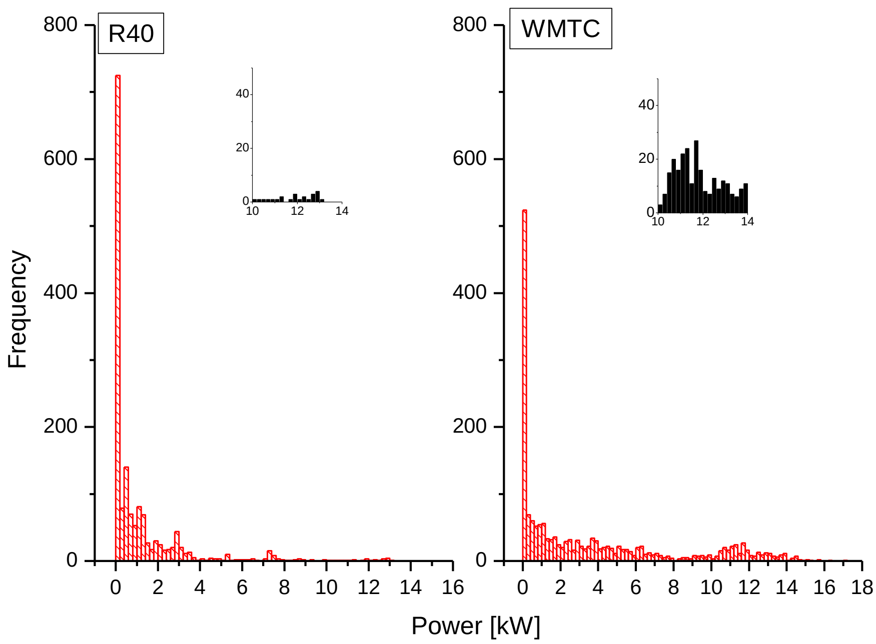


Figure 127. Vehicle 10. Distribution of counts (frequency) for the power on the horizontal axis.

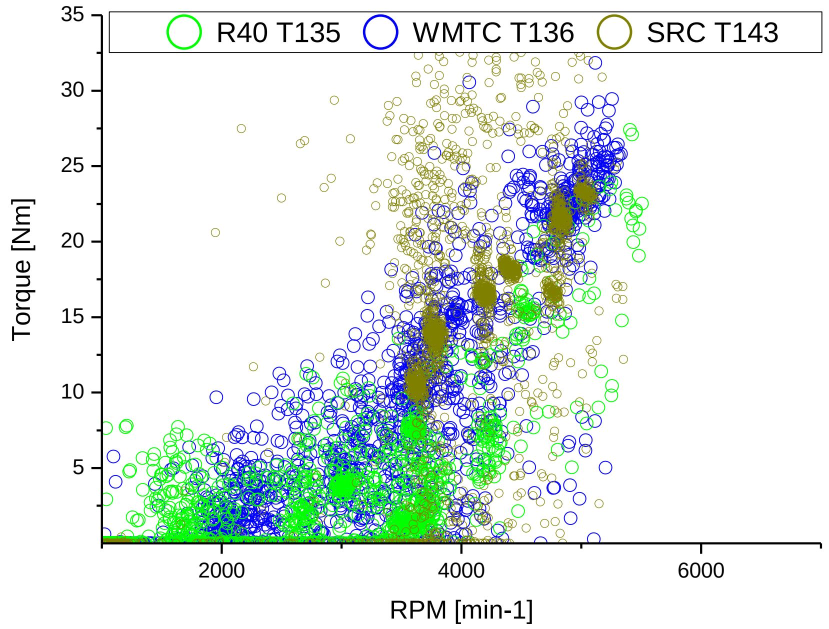


Figure 128. Vehicle 10. Torque (vertical axis) VS engine speed for different driving cycles.

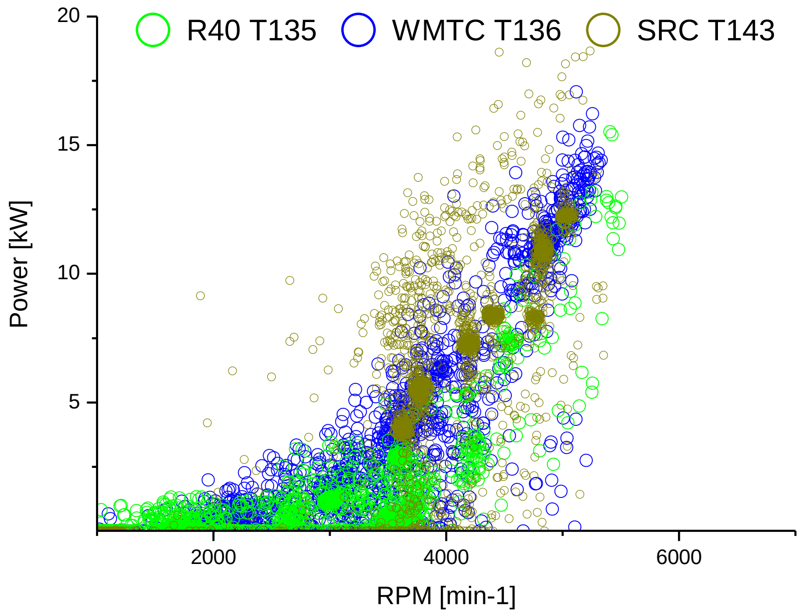


Figure 129. Vehicle 10. Power (vertical axis) VS engine speed for different driving cycles.

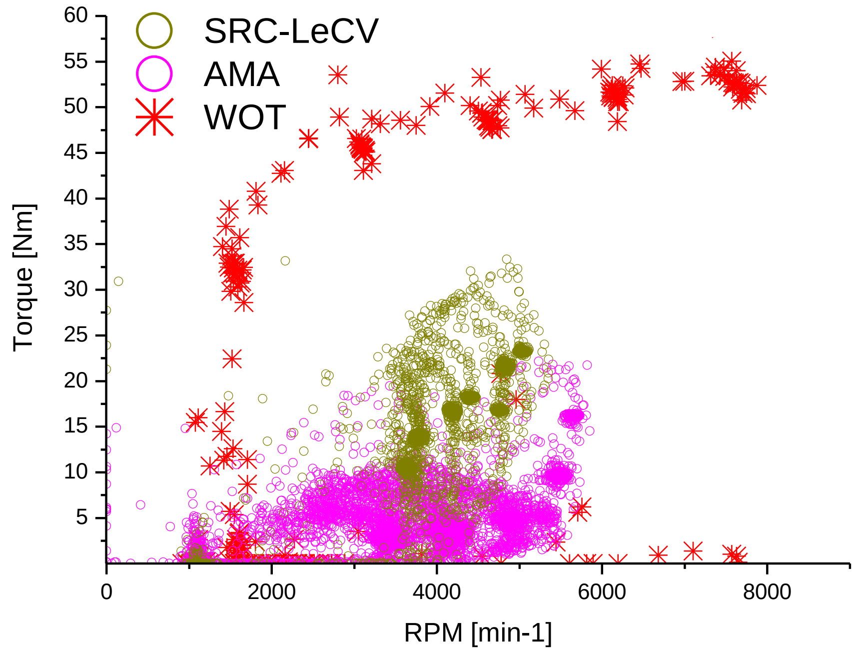


Figure 130. Vehicle 10. Torque VS engine speed for the durability cycles SRC-LeCV and AMA.

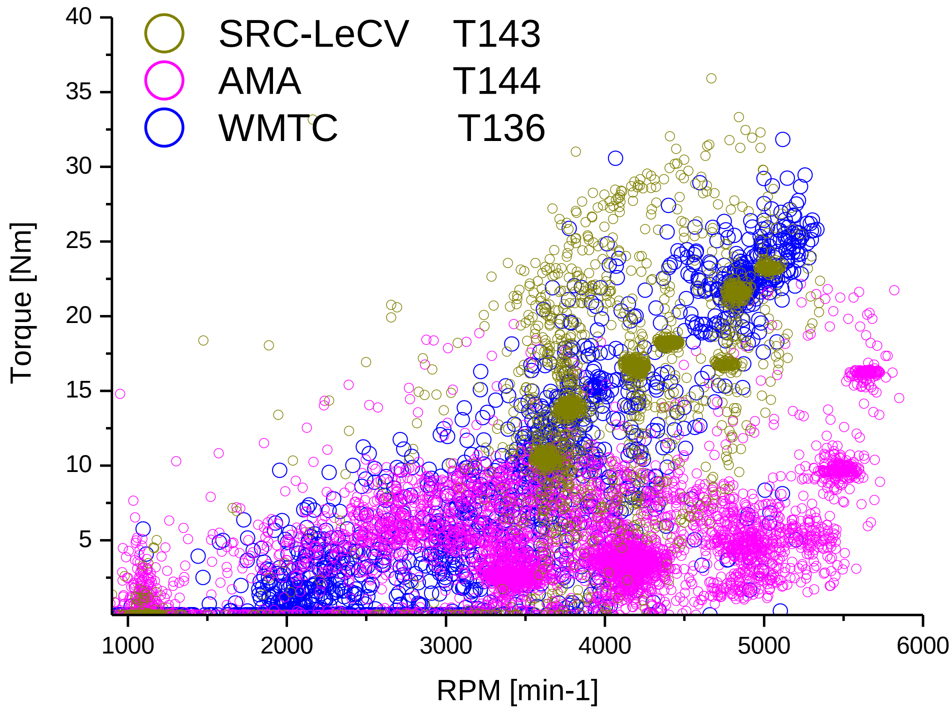


Figure 131. Vehicle 10. Zoom of torque at the wheel VS engine speed for the durability cycles SRC-LeCV and AMA.

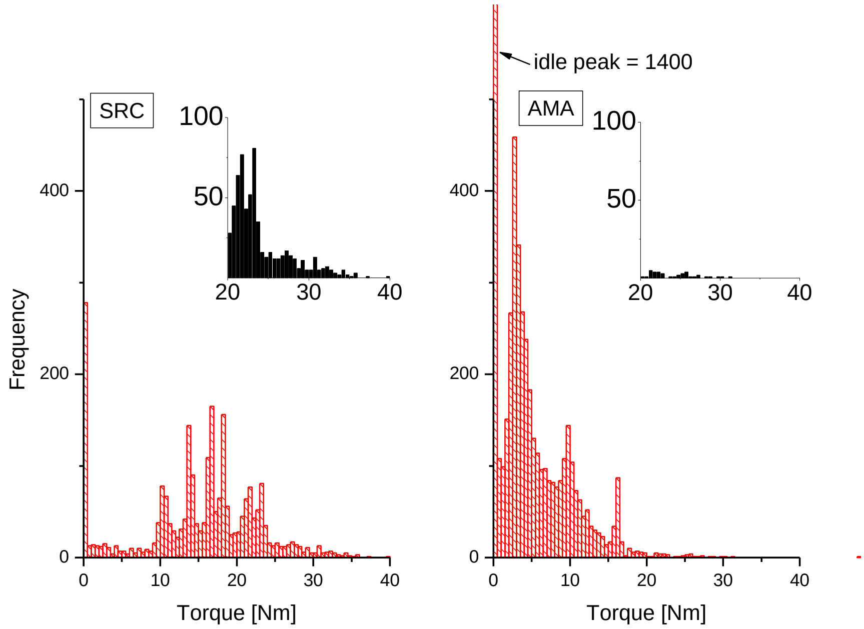


Figure 132. Vehicle 10. Distribution of counts (frequency) for the torque on the horizontal axis for the durability cycles.

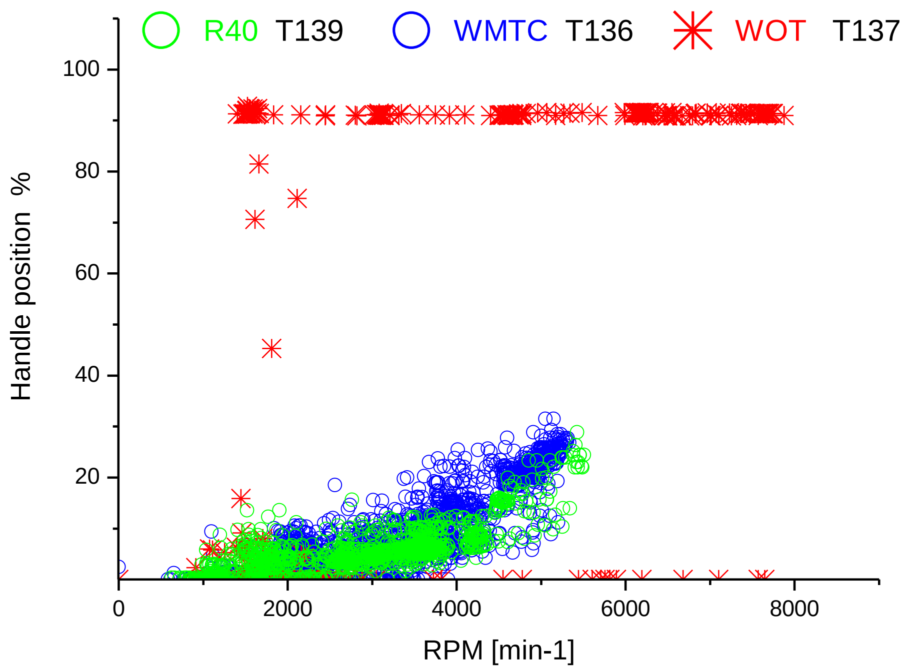


Figure 133. Vehicle 10. Handle position (vertical axis) VS engine speed for different driving cycles.

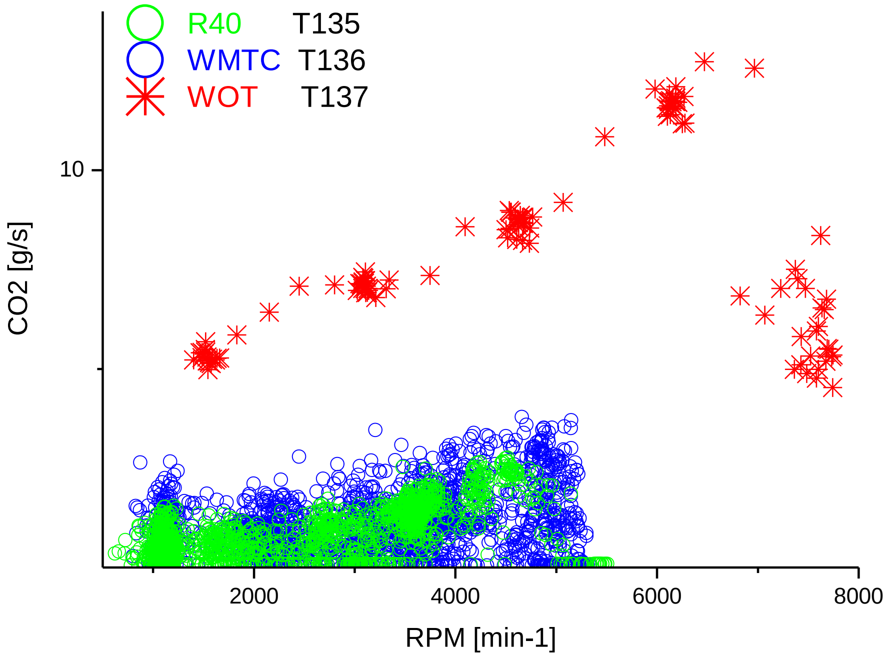


Figure 134. Vehicle 10. CO_2 mass emissions (vertical axis) VS engine speed for different driving cycles.

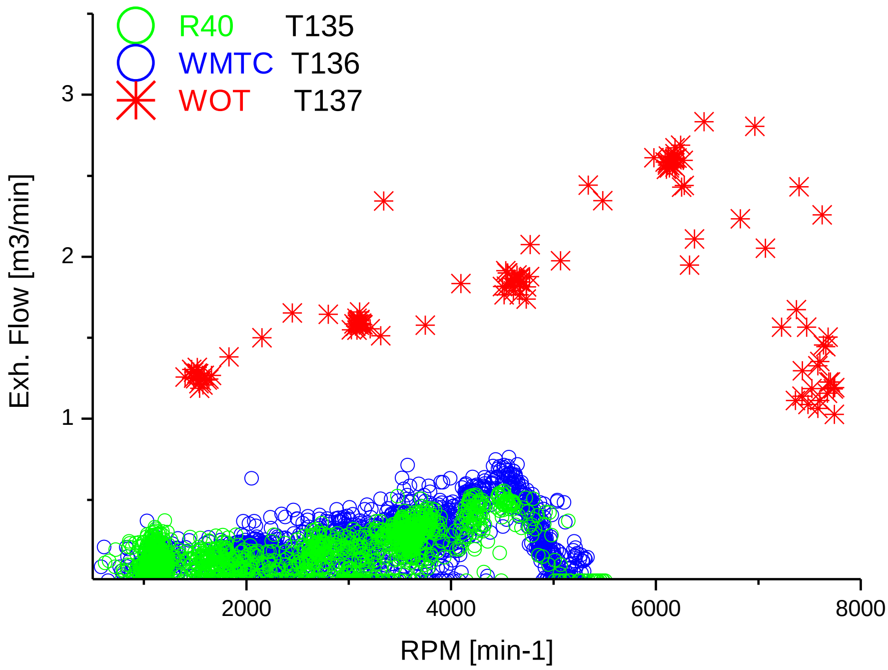


Figure 135. Vehicle 10. Exhaust flow (vertical axis) VS engine speed for different driving cycles.

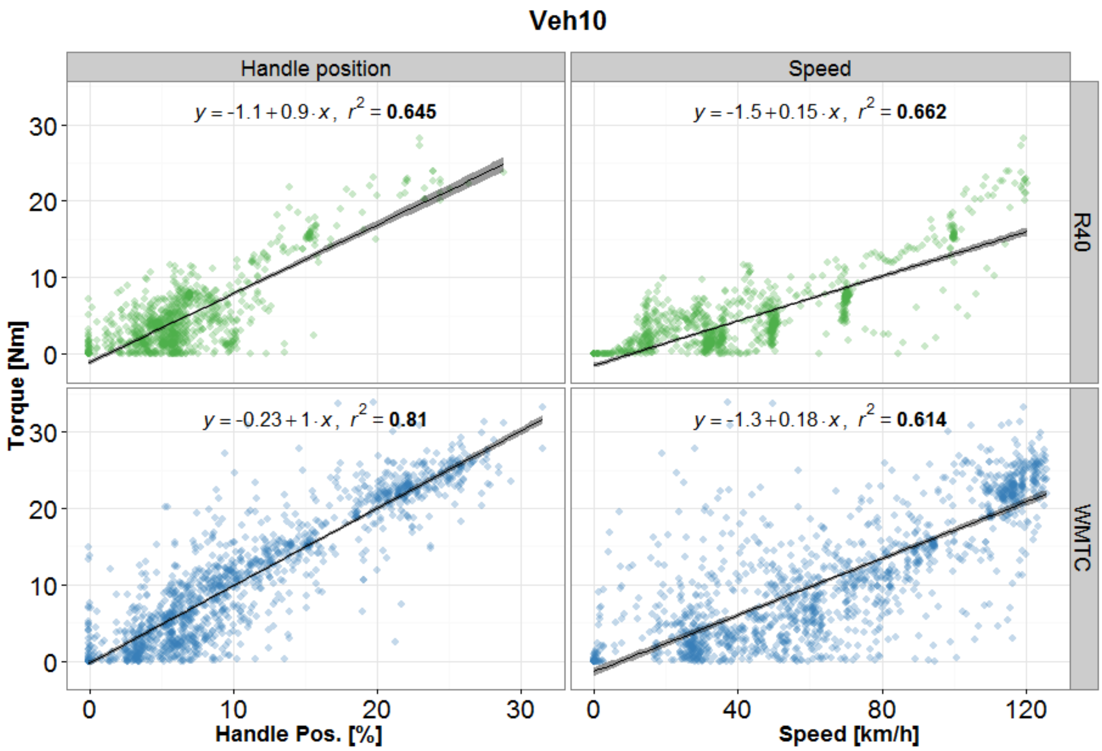


Figure 136. Vehicle 10. Correlation plots of torque VS handle position and speed.

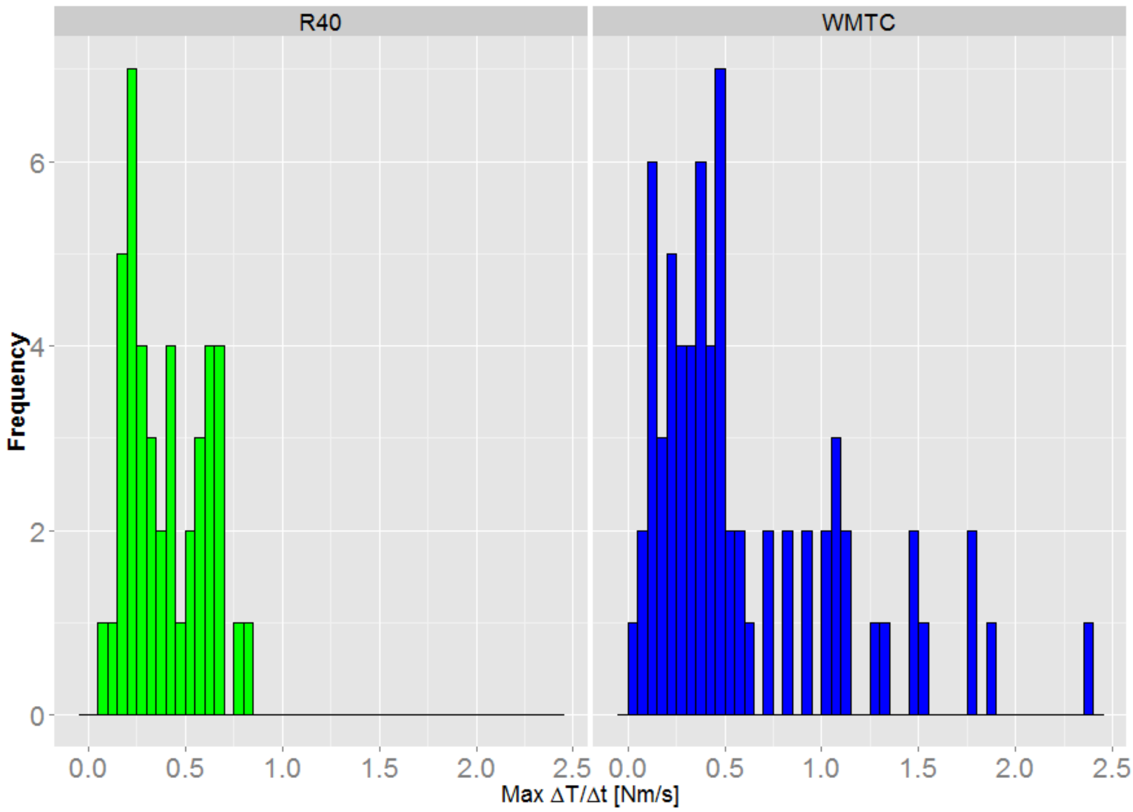


Figure 137. Vehicle 10. *Dynamics* indicator for the assessment of the WMTC.

4.11 Vehicle 11

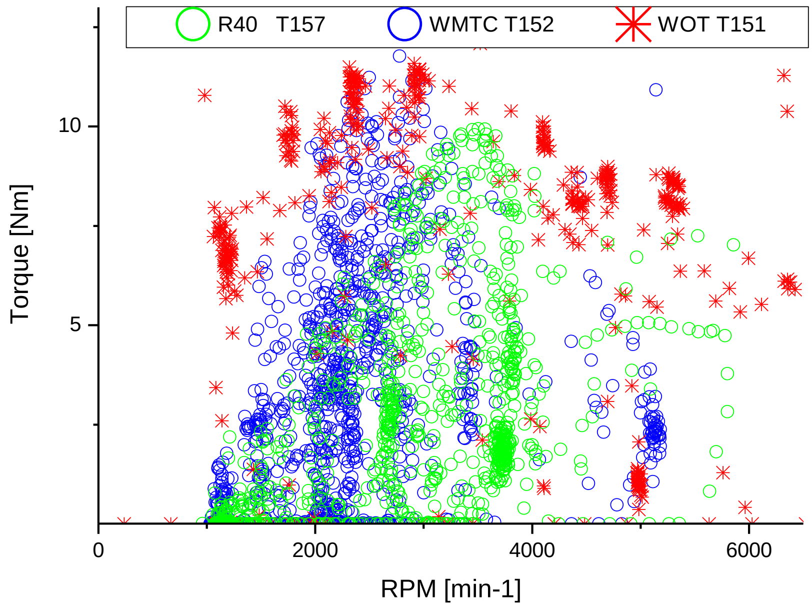


Figure 138. Vehicle 11. Torque (vertical axis) VS engine speed (RPM, min-1) for different driving cycles.

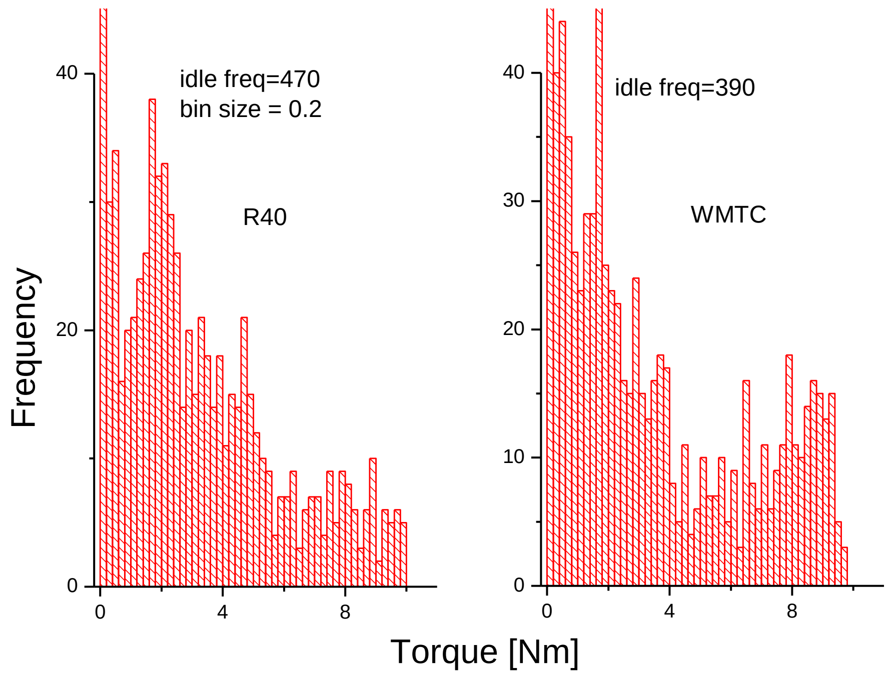


Figure 139. Vehicle 11. Distribution of counts (frequency) for the torque on the horizontal axis.

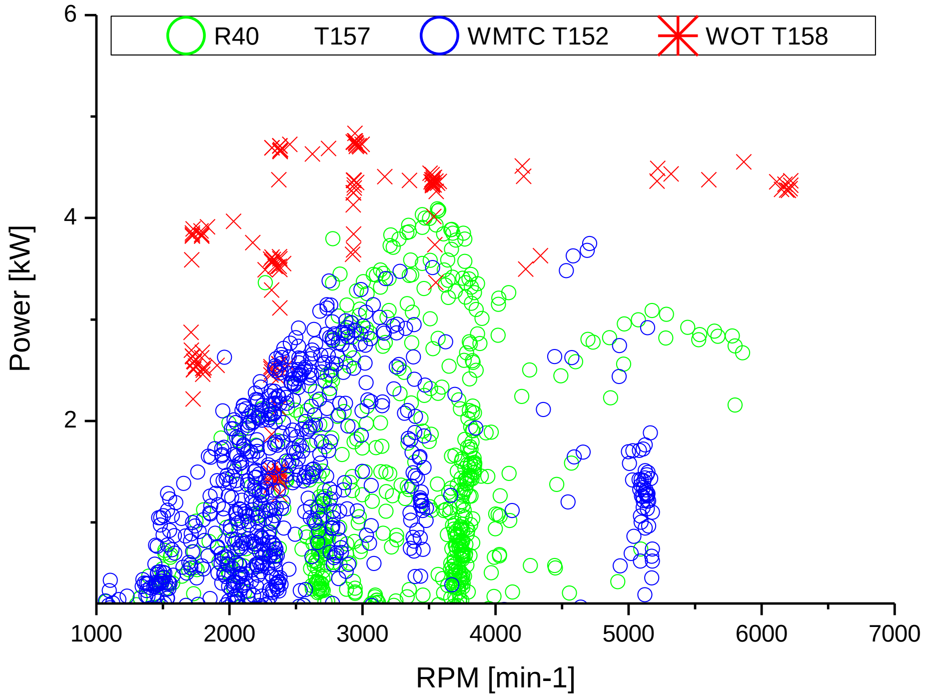


Figure 140. Vehicle 11. Power (vertical axis) VS engine speed for different driving cycles.

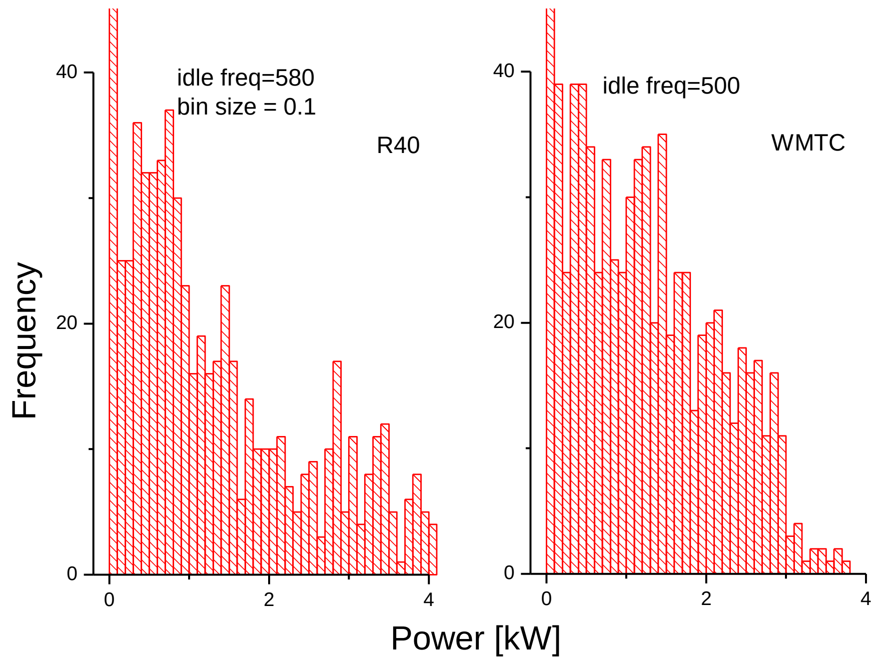


Figure 141. Vehicle 11. Distribution of counts (frequency) for the power on the horizontal axis.

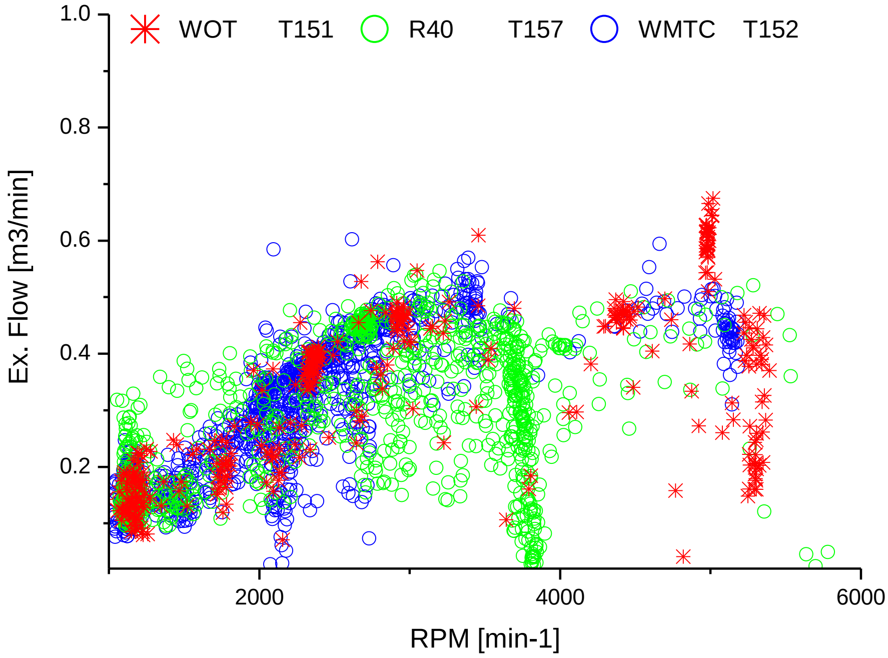


Figure 142. Vehicle 11. Exhaust flow (vertical axis) VS engine speed for different driving cycles.

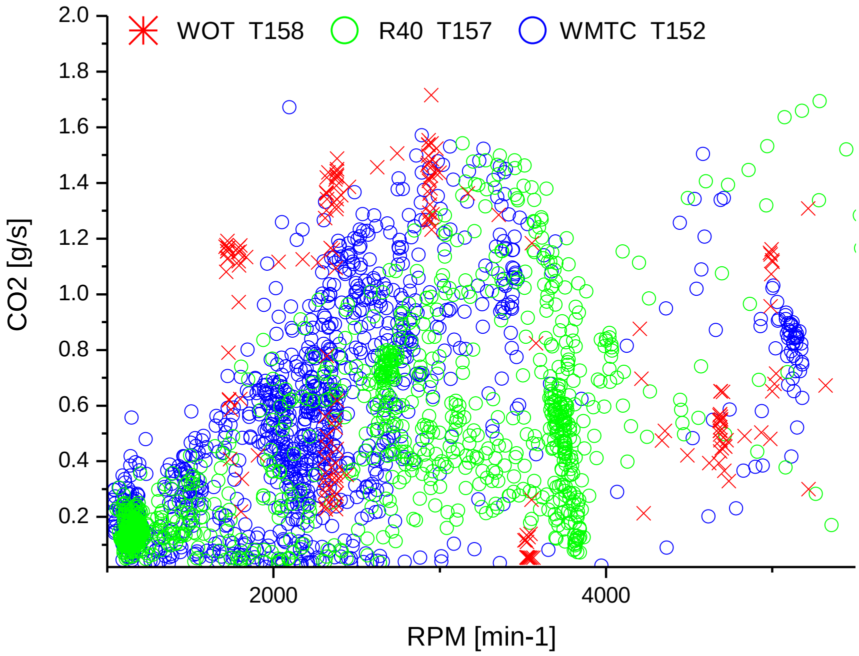


Figure 143. Vehicle 11. CO_2 mass flow (vertical axis) VS engine speed for different driving cycles.

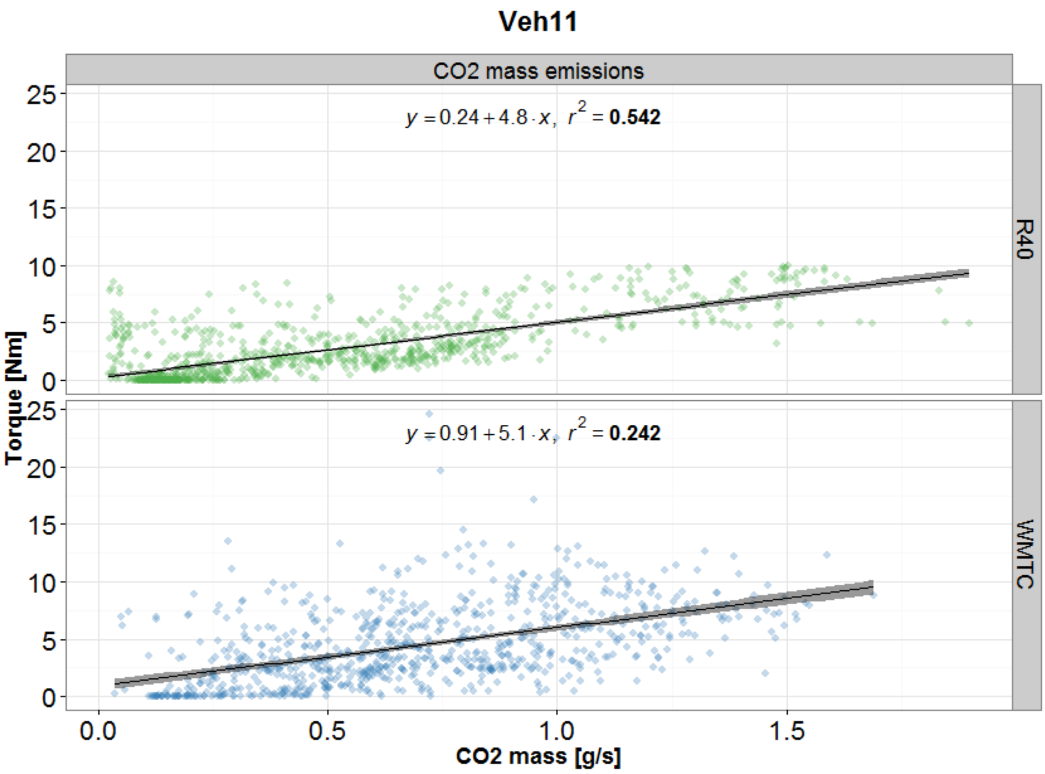


Figure 144. Vehicle 11. Correlation plots of torque VS CO_2 mass emissions.

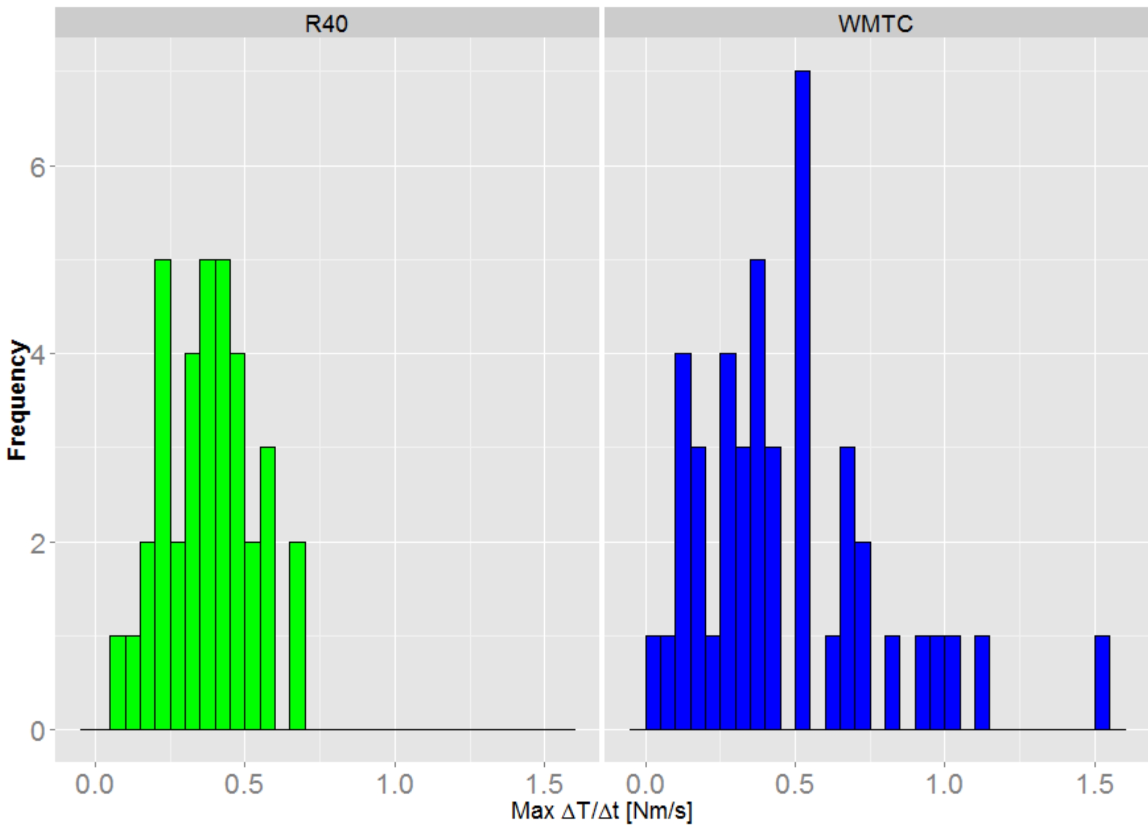


Figure 145. Vehicle 11. *Dynamics* indicator for the assessment of the WMTC.

4.12 Vehicle 12

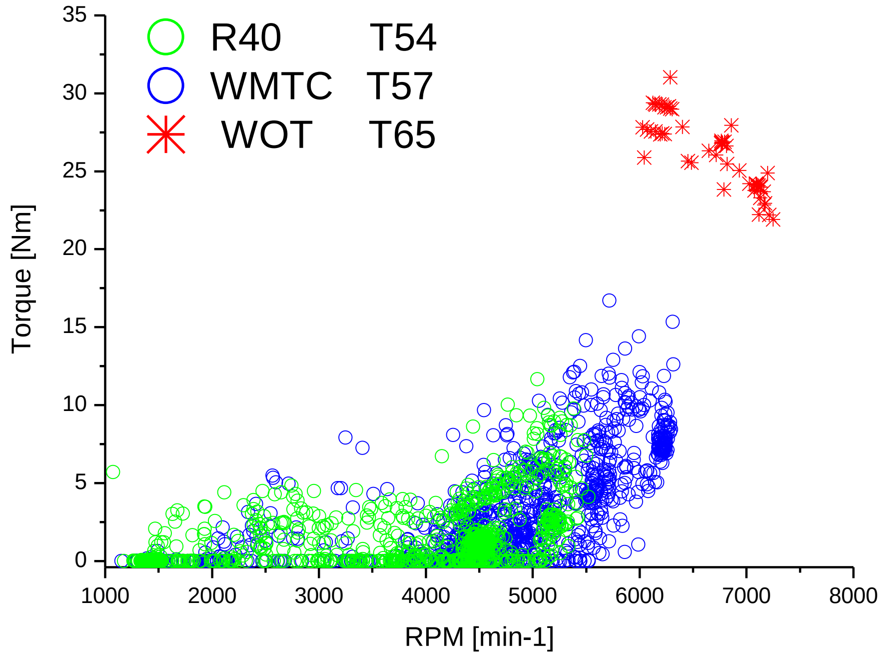


Figure 146. Vehicle 12. Torque (vertical axis) VS engine speed for different driving cycles.

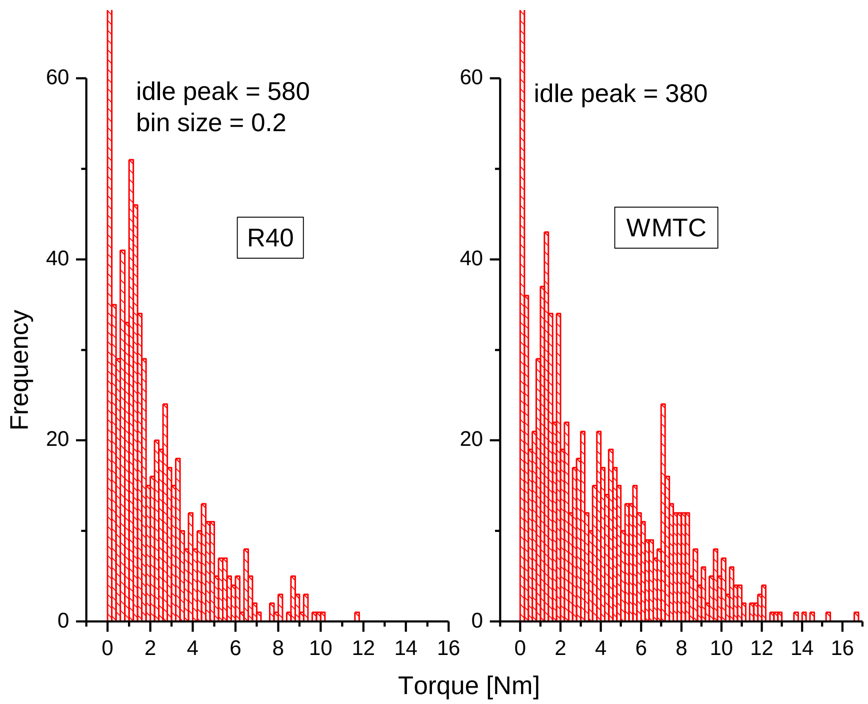


Figure 147. Vehicle 12. Distribution of counts (frequency) for the torque on the horizontal axis.

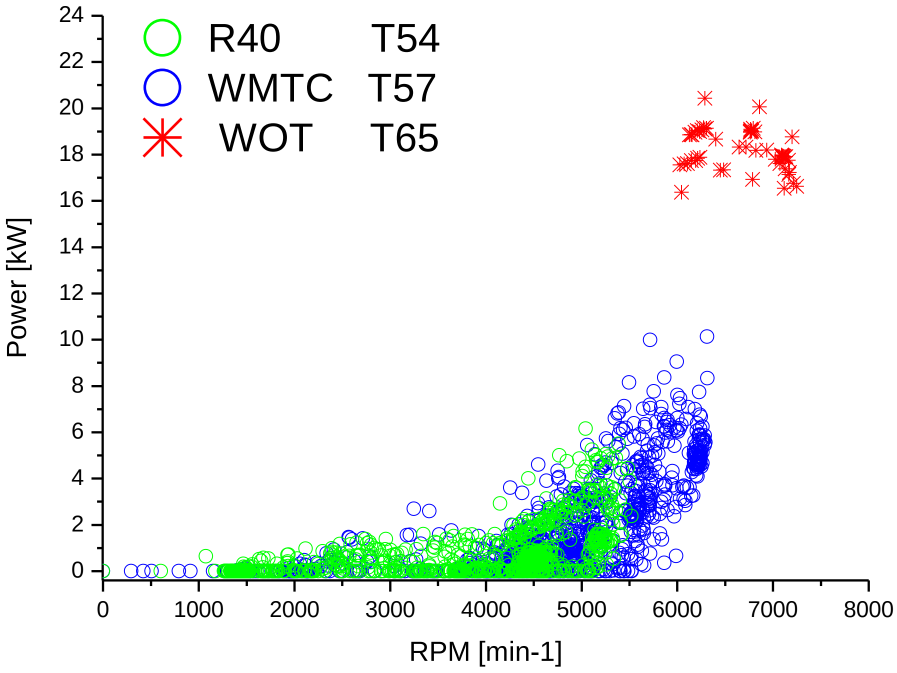


Figure 148. Vehicle 12. Power (vertical axis) VS engine speed for different driving cycles.

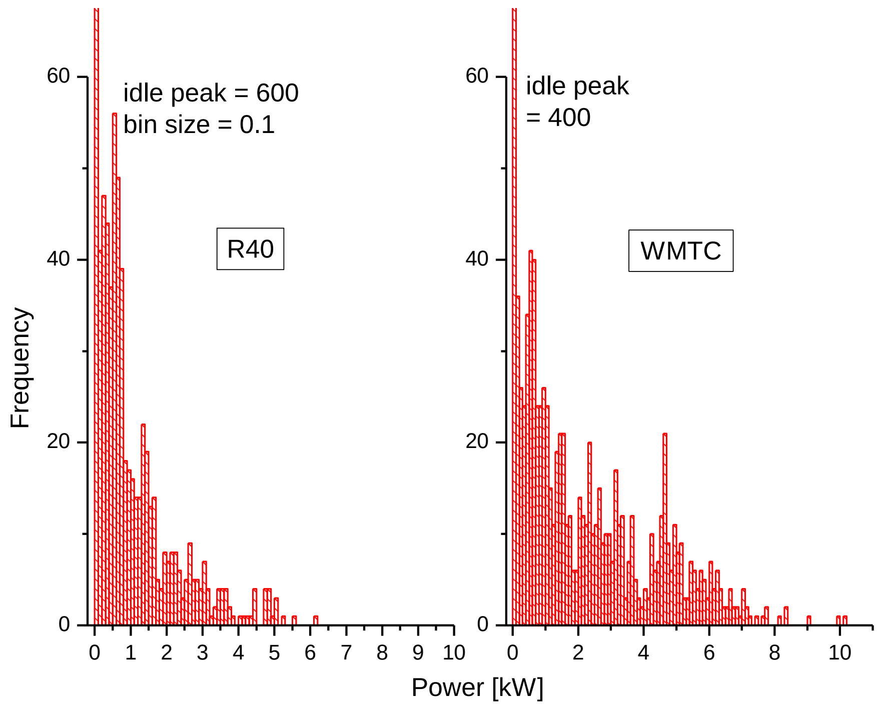


Figure 149. Vehicle 12. Distribution of counts (frequency) for the power on the horizontal axis.

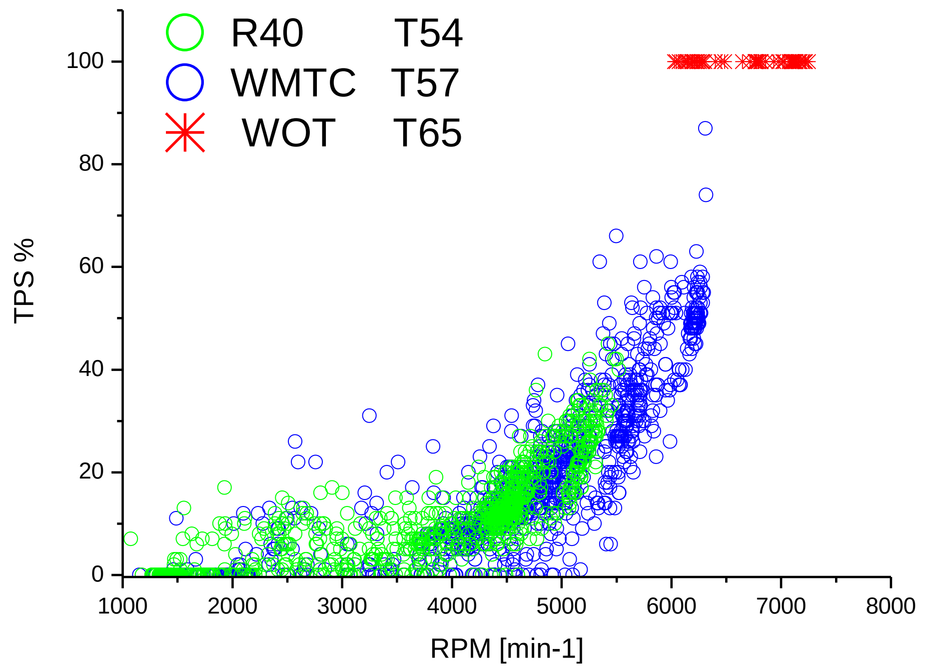


Figure 150. Vehicle 12. Throttle position (vertical axis) VS engine speed for different driving cycles.

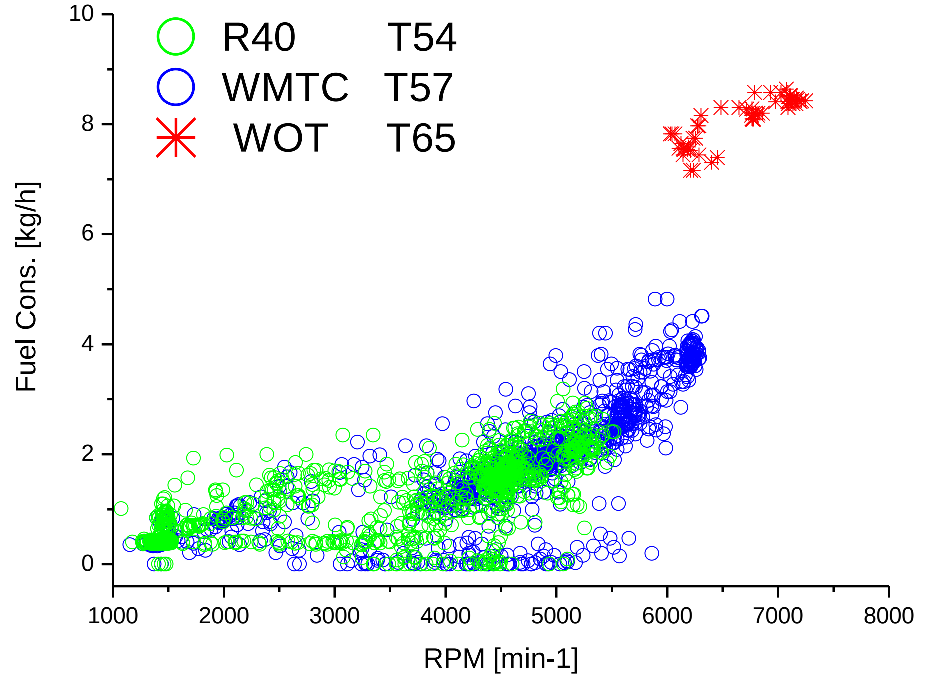


Figure 151. Vehicle 12. Fuel consumption (vertical axis) VS engine speed for different driving cycles.

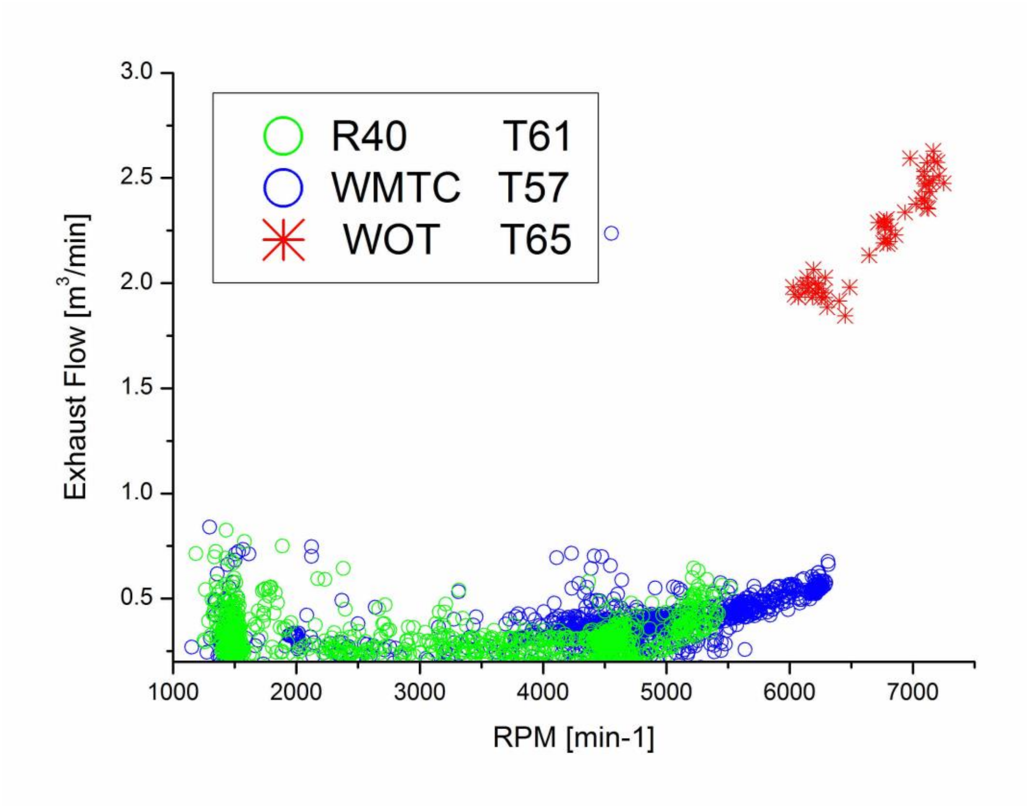


Figure 152. Vehicle 12. Exhaust flow (vertical axis) VS engine speed for different driving cycles.

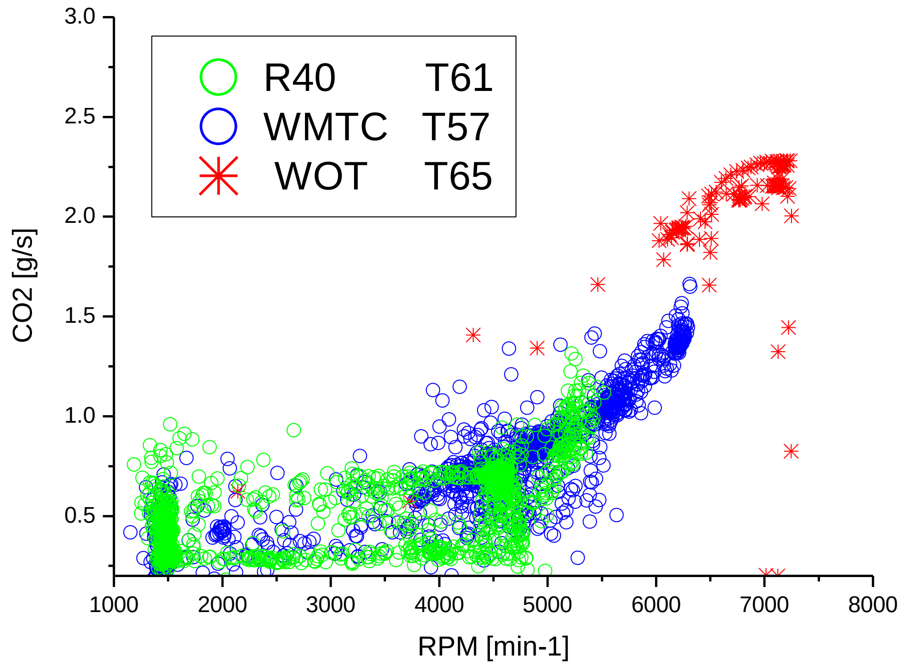


Figure 153. Vehicle 12. CO_2 mass flow (vertical axis) VS engine speed for different driving cycles.

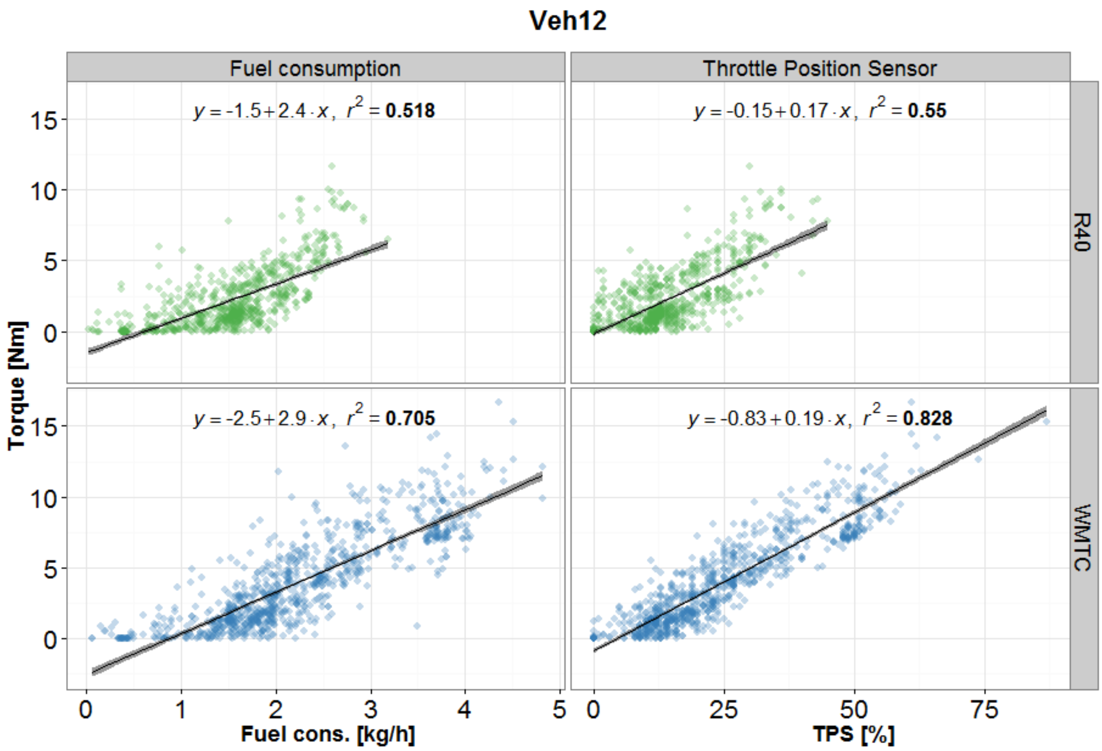


Figure 154. Vehicle 12. Correlation plots of torque VS fuel consumption and throttle position.

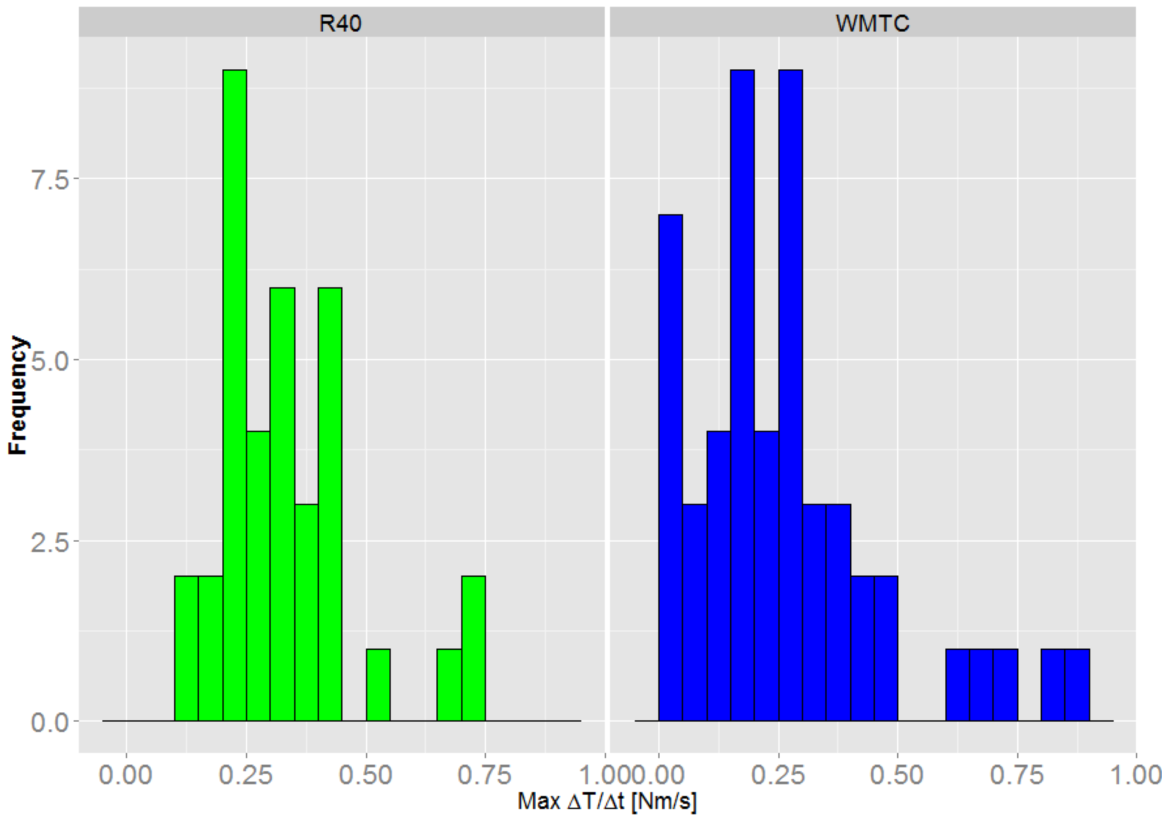


Figure 155. Vehicle 12. *Dynamics* indicator for the assessment of the WMTC.

5. Miniature Test Equipment

Reg.168 and Reg.134 do not require off-cycle exhaust emission measurements. However Recital 12 of Reg.168 calls for a feasibility study of further elements to be included in the Effect Study, among which off-cycle emissions measurements. Measuring real-driving emissions, those produced by the vehicles with internal combustion engine during on-road use, may represent the best approach to assess off-cycle emissions. Nevertheless an approach based on roller bench tests with a speed profile other than the legislative one may achieve the same objective. One of the objectives of the Pre-Study was to identify potential suppliers and to collect literature about miniature on-board emission test devices.

An assessment of real-driving emissions for L-category poses the following problems, which are particularly challenging for the smaller segments of the L-category (L1e-L2e-L3e):

- The portable instrumentation must be smaller and lighter than those normally deployed on passenger cars and heavy duty trucks. The size is related to safety issues and rules applicable to on-road driving when transporting goods (the instrumentation will be most of time attached in open-air to the L-category vehicle). The weight is related to the quality of the measurements and to what degree on-road and legislative measurements can be compared (the weight of additional instruments on the vehicle will influence the emissions);

- The exhaust flow rate of the smaller segments of the L-category can be as small as few liters per minute (idling), likely causing backflow sampling in case of multiple instruments connected at the tailpipe and hardly allowing any direct measurement of the exhaust flow with simultaneous emission measurements.;

Therefore, we recommend

- A maximum weight of 35 kg, including batteries, which is about 50% more than the weight of the average driver according to the legislation;

- A maximum size of 50x50x30 cm (LxWxH), not to exceed the width of a small L1e-B moped;

- A detailed calculation of the exhaust flow rate, which must be validated during roller bench tests.

We collected information about some marketable devices and peer-reviewed scientific articles that can be of input for the above mentioned Task of the Effect Study.

5.1 Identified Suppliers

We could identify only one supplier which sells on the market a portable measurements system specifically designed for small motorcycles (Global MRV, USA, see Table 8). However, as far as we know, there is no scientific literature that describes the performance of such an instrument. Other suppliers offer instruments that are designed for passenger cars or trucks and may be in principle adapted to smaller vehicles such as those in the L-category.

Concerning quadricycles, light commercial vehicles, and mini cars, the same PEMS as the one designed for light-duty vehicles can be used.

Table 8. Potential suppliers for miniature on-board emission test equipment.

Producer	Model	Output	Supply	Weight [kg]	Purpose	On the WEB
Horiba	MEXA-720 NOx	NOx, O2, A/F, Lambda	12 V to 30 V	1	For diesel and Lean-burn engines	http://www.horiba.com
AVL	MOVE	CO, CO_2, NO, NO_2	230V	30	For diesel and petrol engines	https://www.avl.com
Global MRV	AXION	HC, CO, CO_2, NOx, O_2, +PM module +NH_3 module Computed Exhaust flow. Pollutant mass flow.	12 V	8.2-17	Fixed, mobile, marine engines/vehicles.	http://www.globalmrv.com
CO_2 meter	CM-0005 30%	CO_2	Battery	Hand-held	CO_2 ambient monitor	www.co2meter.com

5.2 Literature related to real-driving for L-category

Su, Kao-Chun, Chuang, Chih-Wei, "Exhaust Emissions Characteristics of Scooters on the Real World in Taiwan", JSAE 20139050 / SAE 2013-32-9050

Vojtisek-Lom, M., & Cobb, J. T. (1997): "Vehicle mass emissions measurement using a portable 5-gas exhaust analyzer and engine computer data." Proceedings: Emission Inventory, Planning for the Future.

Vojtisek-Lom, M., Cobb Jr., J.T. (1998): "Measurement, variance and reduction of real-world emissions of 20 dedicated CNG vans." Proceedings of the Air & Waste Management Association's Annual Meeting & Exhibition.

Vojtisek-Lom, M., Fenkl, M., Dufek, M., and Mareš, J. (2009): "Off-cycle, Real-World Emissions of Modern Light Duty Diesel Vehicles, " SAE Technical Paper 2009-24-0148, doi:10.4271/2009-24-0148.

Vojtisek-Lom, M. (2011): "Total Diesel Exhaust Particulate Length Measurements Using a Modified Household Smoke Alarm Ionization Chamber." Journal of the Air and Waste Management Association, ISSN 1047-3289, 61, 126-134.

Vojtisek-Lom, M. (2013): "Assessment of Low Levels of Particulate Matter Exhaust Emissions Using Low-Cost Ionization-Type Smoke Detectors," SAE Technical Paper 2013-24-0168, doi:10.4271/2013-24-0168.

6. Particle Number

During the Pre-Study a particle number (PN) compliant counting system[3] was also used as input to the feasibility study on PN laid down in Reg.168, Recital 12. Especially the subcategory L1e-B of L-category is known to be strong emitter of particle mass (see Rijkeboer, et al., 2005 [7]), but no study addressed so far the particle number issue in a systematic way. Even though the setup was not designed expressly for L-category vehicles, it is the best technology available to assure repeatability of the experiments and to address potential concerns (see below). Details are provided in a dedicated article (Giechaskiel et al., 2015 [8]); only a summary of the study is here provided.

Chronology of EU Regulation concerning PN standards

2009: PN for European diesel passenger cars

2013: PN limit for European heavy duty engines

2014: PN limit for European gasoline direct injection passenger cars

Definition of particles measured by the PMP method

Solid particles that do not evaporate at 350 °C with diameters above 23 nm.

Rationale

Mopeds and motorcycles are strong particle emitters.

Concerns

- The portion of solid particles not counted with the current PN method
- Artefacts below 23 nm due to the large amount of semi-volatile material

Test fleet

5 mopeds, 9 motorcycles, 2 tricycles (one diesel) and 1 quad

Method

PMP compliant systems with counters >23 nm and >10 nm

Additional investigated features

Catalytic strippers, particle counters >3 nm, particle sizers

[3] https://www2.unece.org/wiki/pages/viewpage.action?pageId=2523173

Results

- Artifacts were observed such as particles formation <23 nm, and <10 nm at high load
- Tailpipe vs Dilution Tunnel: >23 nm 10-20%, <23 nm up to 50%
- WMTC vs older cycles: good correlation (same order of magnitude, see Figure 156)
- up to 70% non-counted particles (up to 40% for cars)
- Level of particle number emission is **2-20 times higher** than emission limits for passenger cars (see Table 9).

Conclusions

Based on the results, it is recommended to **use a modified PMP method with a 10 nm cutoff in particle size.** To minimize the presence of artifacts either high dilution ratios or the use of a catalytic stripper (or both) are highly recommended.

Table 9 displays the ratio between the PN level measured for L-category vehicles in this study and the passenger car limit value of PN emissions measured with a PMP compliant system (limit = $6x10^{11}$ particles/km). Orange values are those within one order of magnitude. Based on previous experience, they might fall below limit values once a specific measurement protocol is designed. It is unlikely though that the values up to 20 times the passenger cars limit (values in red) will be reduced below limits just by the choice of an appropriate protocol or reasonable limit value.

Disclaimer

The European Commission is not planning to introduce a particle number limit for L-category vehicles at present. Therefore the results of this study should be considered as input for future feasibility studies. In addition, in this study we apply a measurement protocol that was designed for passenger cars to L-category vehicles, because it is simply the safer and up-to-date procedure that can be followed.

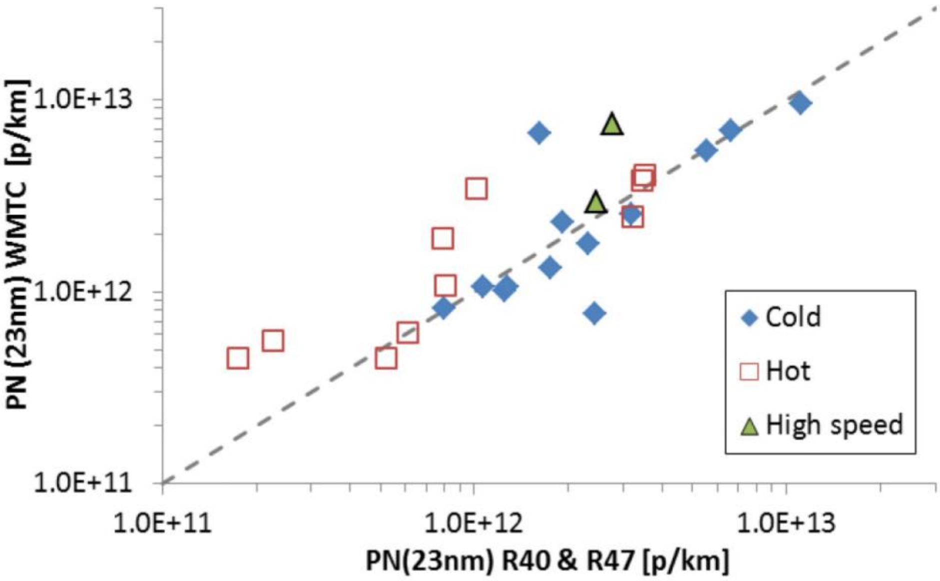


Figure 156. Ensemble graph with all available data and vehicles for particles size >23 nm (Giechaskiel et al., 2015 [8]).

Table 9. Ratio between the PN level measured for L-category vehicles in Giechaskiel et al. (2015) and the passenger car limit value of PN emissions measured with a PMP compliant system (limit = $6x10^{11}$ particles/km).

Vehicle type	PN Level / $6x10^{11}$ p/km (limit for passenger cars)
Moped	**3-20**
Motorcycle	**2-4**
Quad	**12**
Tricycle	**3**

7. Discussion and conclusions

The engine load variables have been compared to the torque at the wheel, considered to be the best proxy for the engine load variable when only vehicle related measurements are possible (whole vehicles are usually available for testing without the possibility of removing the engine and testing it separately on an engine bench test). The attempt to predict the torque at the wheel based on the engine load variables is presented in the first section.

The type approval test procedures contained in Reg.134 include the introduction of the Worldwide harmonized Motorcycle Test Cycle (WMTC). The main scope of this report was to compare the WMTC against the pre- Euro 5 legislative cycles in terms of sampling points of the load versus engine speed matrix under the maximum torque curve. As a consequence the unsampled area between the test cycles and the maximum load can be also evaluated. The indicators used are: Quality, Quantity and Dynamics. The Quality indicator relates to the area covered by the different test cycles; the Quantity is the level and distribution of load reached during the different driving cycles; the Dynamics is the change in load compared to the time needed for that change. The correlation between the engine loads variables was investigated and compared to the torque at the wheel (best proxy for the engine load variable). The main results related to the Quality, Quantity and Dynamics are presented in the second, third and fourth sections respectively.

Two distance accumulation cycles were investigated during this study (e.g. SRC and AMA). The differences in terms of Quality, Quantity and Dynamics are discussed in the sixth section.

Finally, the last section summarizes the key findings and the recommendations for the Euro 5 Effect Study.

7.1 Load variables

The correlation between torque and the different load variables was investigated. Table 7 lists the engine load variables monitored for every vehicle tested.

As a first step, a simple linear regression model was built considering the torque as dependent variable and each engine load variable as predictor. Table 10 presents the adjusted r-squared obtained for each engine load variable and vehicle for WMTC tests.

The adjusted r-squared between engine load variables and the torque can be sorted into three categories: non-correlated ($R^2 < 0.6$), fairly-correlated ($0.6 \leq R^2 \leq 0.8$), and well-correlated ($R^2 \geq 0.8$).

Correlation capability was vehicle dependent; however, a general trend can be drawn. Relevant variables identified in this correlation exercise could be the throttle position, the manifold absolute pressure and to a lesser extent, the handle position.

Table 10: Summary of adjusted r-squared (R^2) obtained from linear regression model of torque variable and the investigated load variables for all the vehicles studied over the WMTC. Green fill stands for well-correlated ($R^2 \geq 0.8$), orange for fairly correlated ($0.6 \leq R^2 \leq 0.8$) and red for non-correlated ($R^2 < 0.6$) engine load variables.

	Sub-categories	β_{CO2}	$\beta_{Fuel\ Cons}$	$\beta_{Handle\ position}$	$\beta_{Exhaust\ flow}$	$\beta_{Vehicle\ speed}$	β_{MAP}	$\beta_{Throttle\ position}$
Veh1	L1e-B	0.0776	0.0857	0.3939	0.2912	0.0437		
Veh2		0.0544	0.0561	0.1815	0.3818	0.0472		
Veh3		0.5098	0.1229	0.4532	0.4399	0.1002		
Veh4		-0.0011	0.0597	0.0126	0.0045	0.1582		
Veh5		0.3234	0.1946		0.3314	0.0249		
Veh6	L3e-A1	0.3576	0.0253	0.4570	0.3595	0.1908	0.7653	
Veh7	L3e-A2	0.4260	0.7347	0.3229	0.4190	0.2617		
Veh8	L3e-A2	0.8044	0.7950	0.8170	0.7420	0.5892		0.8508
Veh9	L3e-A3	0.3561			0.4039	0.5440		0.7242
Veh10	L3e-A3	0.0217		0.8103	0.0124	0.6139		
Veh11	L5e-B	0.2819			0.0423	0.0364		
Veh12	L7e-A1	0.3659	0.7042		0.1975	0.2881		0.8279

The best variables by sub-categories were:

- **L1e-B**: Overall, no engine load variable appeared to be neither well nor fairly correlated with the torque. With an adjusted r-squared of 0.51, linear model built with CO_2 mass emission for Veh3 provided the best prediction of torque during WMTC. Among L1e-B category vehicle tested, Veh3 displayed the best prediction results of torque. It is particularly noticeable that the latter vehicle was the only L1e-B category vehicle studied equipped with manual transmission.

- **L3e-A**: When monitored, the throttle position appeared to be the best predictor of torque together with the manifold absolute pressure (fairly- to well-correlated variables). Then, the handle position was rather-correlated to torque for half of the L3e-A vehicles equipped with the handle position sensor. Except for the low performance motorcycle Veh6, the fuel consumption was fairly-correlated to the torque. It is worth noting that almost all load variables monitored were fairly- or well-correlated for the specific Veh8.

- **L5e-B**: The load variable monitored for this tricycle appeared to be non-correlated to the torque. However, overall relevant load variable identified in this study (throttle position, manifold absolute pressure and handle position) were not registered for this vehicle.

- **L7e-A**: For this vehicle, the throttle position and fuel consumption were found to be respectively well and fairly-correlated to the torque.

In the simple linear models described above, the assumption was made that torque could be predicted using one engine load variable. From the correlation plots, it appears clearly that this assumption was too restrictive for some vehicles and improvement of torque prediction could be expected by fitting multivariable model, using a combination of engine load variables. Therefore, as a second step, the combination of engine load variables was investigated with the following methodology.

- First an analysis of variance (ANOVA) was used to investigate the relationship between torque and the engine load variables. From this analysis, variables associated to p-value higher to 0.05 were removed.

- Then, the possible confounders were identified by looking at the relationship between the remaining engine load variables. Variables displaying a correlation higher than 0.85 were selected. Among these pairs of variables, the one associated to the higher correlation to the torque was kept while the other was discarded from the subsequent analysis.

- Finally, the remaining variables were tested to fit the multivariable model using a stepwise model selection by Akaike Information Criterion (AIC).

The final multivariable models obtained for each vehicle are presented in **Error! Reference source not found.**. Multivariable models improved the prediction of torque for all the vehicles, except for Veh6. For the latter vehicle, the MAP was measured during tests when the other engine load variables were not monitored, consequently, the final multivariable model did not take into account this variable. However, the adjusted r-squared obtained for the multivariable model remained greater than the one computed for the simple linear models (i.e. MAP excluded). The improvement associated to the multivariable model was found substantial for vehicles for which the best simple linear models were poor (i.e. Veh4 and Veh11). For vehicles displaying rather good simple linear models, the adding value of multivariable models was quite low.

Overall, the torque was well correlated to the engine load variables for three vehicles (Veh8, Veh10 and Veh12), and fairly correlated for other four (Veh3, Veh6, Veh7 and Veh9).

Table 11: Summary of the coefficients used in the final multivariable models between the torque and the investigated load variables for all the vehicles studied over the WMTC. Grey cells stand for not measured variables. Black cells stand for variables measured but not included in the multivariable model, either based on ANOVA of the β coefficients (p-value> 0.05) or based on the stepwise model selection by Akaike Information Criterion (AIC). c. stands for confounder. R^2 displays the adjusted r-squared of the multivariable model, with in brackets the best adjusted r-squared obtained from the simple linear model. *MAP not measured at the same time as the other engine load variables.

	Sub-categories	β_{CO2}	$\beta_{Fuel\ Cons}$	$\beta_{Handle\ position}$	$\beta_{Exhaust\ flow}$	$\beta_{Vehicle\ speed}$	β_{MAP}	$\beta_{Throttle\ position}$	R^2
Veh1	**L1e-B**	-0.5	-0.74	0.02	c. with Handle position				0.4467 (0.3939)
Veh2		0.41	-0.25		6.46				0.3947 (0.3818)
Veh3		3.17		0.02					0.6078 (0.5098)
Veh4		c. with Exhaust Flow		0.01	3.17	-0.04			0.3774 (0.1582)
Veh5		c. Exhaust Flow	0.53		9.28	0.003			0.3594 (0.3314)
Veh6	**L3e-A1**	0.61		0.05		0.014	*		0.5523 (0.7653)
Veh7	**L3e-A2**		5.08	-0.03	c. with CO2				0.7411 (0.7347)
Veh8	**L3e-A2**	c. with Throttle position	c. with Throttle position	c. with Throttle position	c. with Throttle position	c. with Throttle position		0.17	0.8508 (0.8508)
Veh9	**L3e-A3**	c. with Exhaust Flow			2.6	0.013		0.50	0.7323 (0.7242)
Veh10	**L3e-A3**	0.26		0.94	c. with CO2	0.016			0.8125 (0.8103)
Veh11	**L5e-B**	9.7			-18	0.033			0.4378 (0.2819)
Veh12	**L7e-A1**	-4.0	c. with Throttle position		-0.97	c. with CO2		0.25	0.8738 (0.8279)

7.2 Quality

The Quality indicator described in Chapter 3 was investigated for the 12 vehicles under study.

7.2.1. Driveability

The driveability was in general good for all vehicles with some exceptions for mopeds, see Table 12. An example is given in Figure 157 for Veh1. Vehicle 11 (tricycle), the only fueled with diesel, exhibited problems in following the speed trace during the first acceleration, with the engine running in cold conditions. Note that the same problems for Veh1, 2, 11, are reported for both the old statutory cycle and the new WMTC. This means that for the vehicles studied in this work the WMTC did not represent an additional technical demand. The Effect Study will have to investigate further this issue and identify whether some sub-categories of the L-category family find it problematic to follow the WMTC speed trace.

Table 12. Driveability parameter for the evaluation of the Quality indicator. Green = no violations neither in accelerations nor maximum speed reached. Orange: violations either in accelerations (A) or maximum speed (S) reached. There are no cases for which both accelerations and maximum speed were not reached.

	Statutory cycle	**WMTC**
Veh1	S	S
Veh2	S	S
Veh3		
Veh4		
Veh5		
Veh6		
Veh7		
Veh8		
Veh9		
Veh10		
Veh11	A (when cold)	A (when cold)
Veh12		

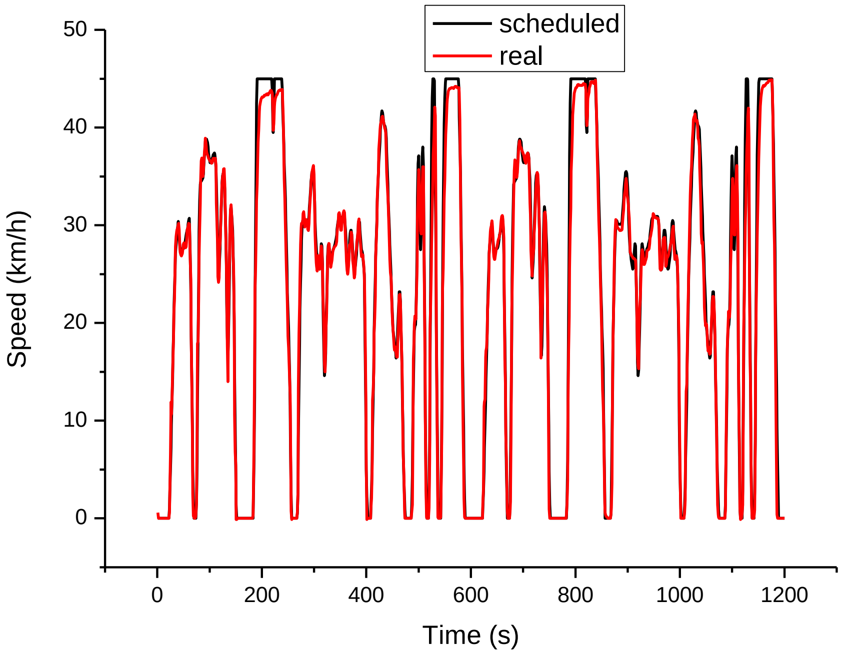


Figure 157. Vehicle 1, example of driveability. The maximum speed of 45 km/h could not be reached in the first acceleration events, while the accelerations are followed without violations.

7.2.2 Sampling area

The area covered by the test/sampling points in the torque versus engine speed plots presented in the previous Chapter was assessed in a semi-quantitative way by assigning an elemental area to each sampling point and by fixing at 100% the area below the torque curve obtained during the wide open throttle test (maximum torque). An example is plotted in Figure 158.

In 2 cases, Veh6 and Veh7, the WMTC was not better in quality than the statutory cycle in use so far. As for Veh6, the two cycles exhibited no clear difference. For Veh7 instead the statutory cycle (R40 incl. EUDC) is more demanding than the WMTC (Sub-class 2-1). For all the other vehicles the WMTC proved to be a better driving cycle in terms of area sampled under the maximum torque curve (see Table 13).

The WMTC type 1 underestimated the potential of L3e-A1 vehicles (low performance motorcycles) when their maximum speed and engine displacement were below 100 km/h and 150 cm^3. The same situation occurred for L3e-A2 vehicles when subjected to WMTC 2-1 (Veh7) and not WMTC 2-2. The impact of this result is enhanced by the European market statistics that sees L3e-A1 and A2 amongst the best seller in the L-category vehicles [internal communication from manufacturers associations].

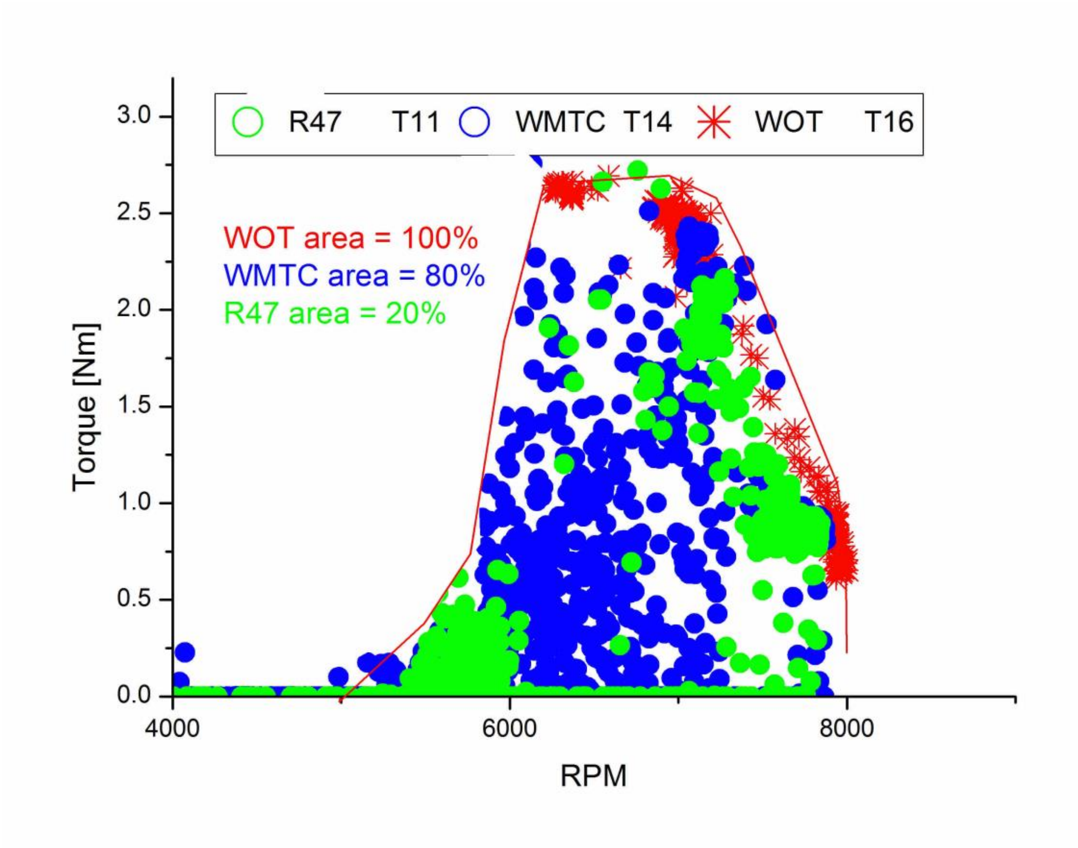


Figure 158. Example of Quality indicator (sampling area) evaluation. An area of 100% is assigned to the region under the WOT curve (max torque). The sampling areas of the WMTC and R47 cycles are assessed based on the sampling points coverage under the WOT curve.

Table 13. Comparison of statutory cycle (R40 and R47) with WMTC in terms of quality of the sampling points. Values refer to the percentage of area covered by the torque under the max torque curve (100%). Green fills stand for higher coverage of WMTC VS statutory cycle. The opposite holds for the orange fills.

	WMTC	**Statutory cycle**
Veh1	80	20
Veh2	80	30
Veh3	40	20
Veh4	40	20
Veh5	50	20
Veh6	20	20
Veh7	40	50
Veh8	50	30
Veh9	30	20
Veh10	30	20
Veh11	60	50
Veh12	40	30

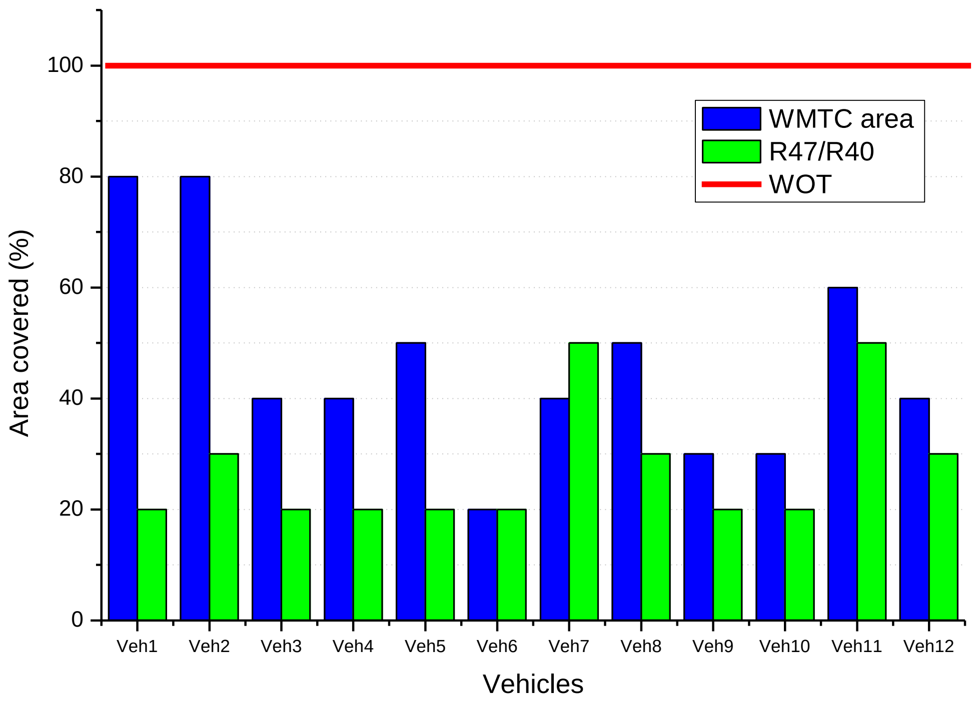


Figure 159. Quality indicator evaluation summary in terms of area covered by the sampling points of the torque variable with respect to the WOT cycle area. See text for details.

7.3 Quantity

The Quantity indicator described in Chapter 3 was investigated for the 12 vehicles under study. Frequency distributions of the torque variable have been plotted for all vehicles in the previous Chapter.

The quantity of sampling points is assessed in terms of:

- *Zero load* points

- *High load* points.

7.3.1 Zero load points

Idle points generally mean lower emissions as the exhaust flow in idle is much lower (down to few liters per minute) than the exhaust flow (up to several hundred liters per minute), regardless of the good / bad combustion of the vehicle at low regimes. This may not hold when analyzing unregulated pollutants that are not in the scope of this study (see e.g., Platt et al. 2014 [9]). Considerations on idling points can be done from technical Tables such as Table 5.

In this work we focused instead on zero load points, the points at zero torque in the frequency distribution plots. In Table 14 the relative importance of zero load points compared to the total duration of the cycle is given. The results for mopeds are different than for the other categories: in terms of zero load, the old regulatory cycle is more demanding than the new WMTC. In other words, during the R47 cycle the zero load points count 0% up to 7% less compared to the total cycle duration than the WMTC. The opposite is true for other categories as the L3e motorcycles, where the torque at the wheel is zero for a shorter period of time, from 8% up to approx. 20%. This means that the WMTC is not more demanding than the R47 for the propulsion unit when the zero load condition is considered.

Note that the prescribed idle points (zero speed) are 13% and 19% of the entire cycle duration for R47 and WMTC-1, respectively, with a net 6% difference that falls in the range of the zero load we identified above. As for motorcycles, a 10-14% less idling (WMTC 2-1 and WMTC 3 compared to EUDC, normalized to the cycle duration) can be associated with up to 18% less zero load points.

Table 14. Impact of the zero load regimes in the old statutory driving cycle and the new WMTC. The values are normalized zero load duration over the entire cycle duration, in difference of percentage (WMTC minus pre-Euro 5 cycle) for the 2 driving cycles. Positive values mean that the WMTC exhibits larger period of zero torque with respect to the pre-Euro 5 cycles (points are normalized to the duration of the cycle).

Vehicle	Zero torque difference [%]
v1	6
v2	4
v3	0
v4	7
v5	7
v6	-8
v7	-12
v8	-18
v9	-18
v10	-17
v11	-20
v12	-18

7.3.2 High load points.

As discussed above, the results for zero load points will not have a major impact on the total emissions, while the sampling points at high load will dominate the emission behavior of the vehicle. The quantification of the impact on the emissions will be given in the following Effect Study (see Appendix 2). In this report we observed the differences in distribution of high load points between the WMTC and the pre-Euro 5 cycles.

The high load region is better covered by the WMTC for all vehicles, as shown in the frequency plots in the previous Chapter, the only exception being Veh7 for the reasons explained above (Section 7.1). In order to quantify the share of pre-Euro5 and WMTC contributions, the torque values included in the range of 70% to 100% of the maximum torque achieved, was selected for each vehicle and defined as the *high load* region of sampling points. Inside this *high load* region, the attribution of sampling points to either to the pre-Euro 5 cycle or to the WMTC was calculated, see Figure 160.

In summary, the frequency and intensity of the torque variable is higher for the WMTC than it is for the pre-Euro 5 test cycles, for all vehicles except one justified exception.

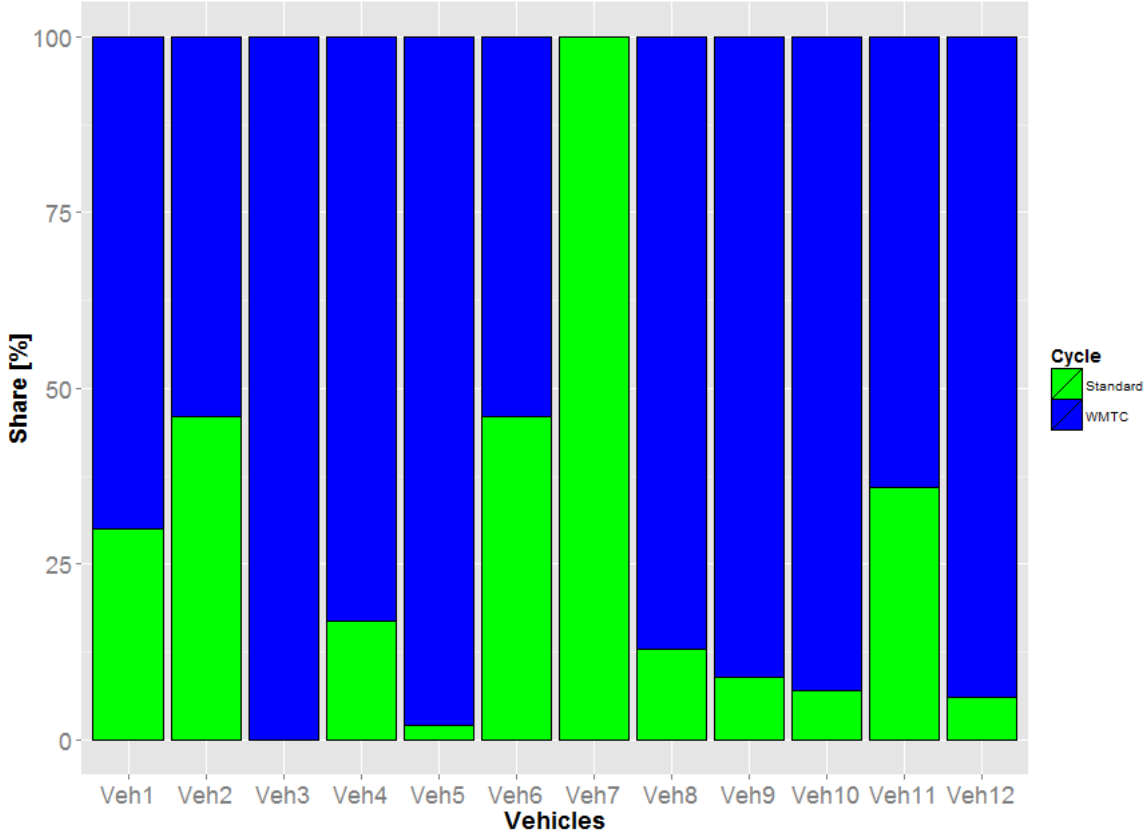


Figure 160. Quantity indicator summary. Share of WMTC and pre-Euro 5 cycles ("standard" in the legend). See text for details

7.4 Dynamics

The changes in torque during the test cycles were calculated with respect to the time needed for those changes to occur during acceleration period. The distribution of the Δ(torque)/Δ(time) variable (torque rate) is displayed in the plots of the previous Chapter for each vehicle. Using the same approach of Section 7.3 for the Quantity variable (*high dynamic load* region of the upper 30% of values), the evaluation shows that the WMTC is more dynamic than the pre-Euro 5 cycle. One exception is Vehicle 6 for the reasons explained above in Section 7.2.

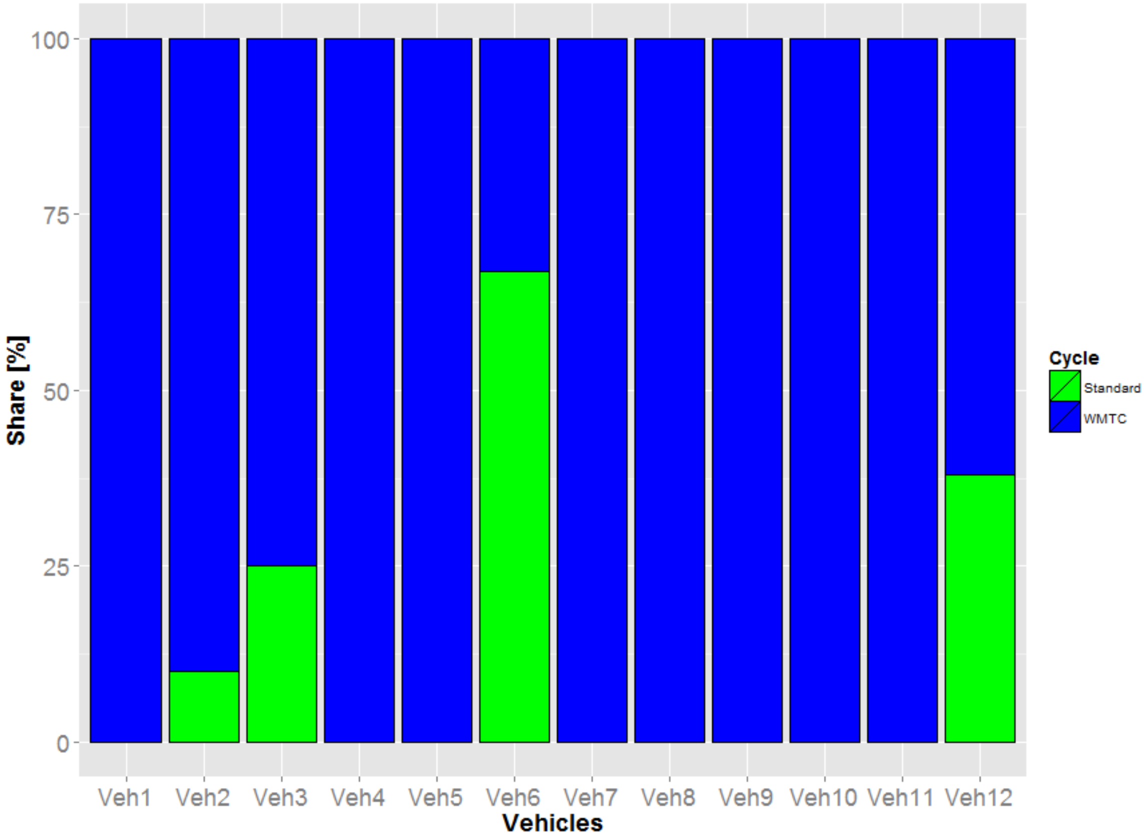


Figure 161. Summary of the Dynamics indicator with the share of high load points (upper 30% of torque values) attributed to the pre-Euro 5 and WMTC cycles, see text for details.

7.5 SRC and AMA distance accumulation cycles

As an example we tested Veh10 over both the SRC-LeCV cycle and the AMA cycle (see Chapter 3 for descriptions). As can be seen from Figure 130 and Figure 131 the SRC cycle better reproduce the operation range covered by the WMTC. In fact, the standard road cycle is a durability test cycle that should simulate speed load points in which the L-category vehicle would also be operated when conducting its type I emission laboratory test, WMTC. In addition, the SRC cycle is twice as fast to run compared to the AMA cycle. An example of Quantity for the SRC and AMA cycles is plotted in Figure 132. The SRC cycle clearly covers a larger range than the AMA and in particular the high-load region is better covered (insets in the plot of Figure 132). We calculated a share of SRC:AMA=0.91:0.09 for the upper 30% values of the torque variable.

While the AMA cycle is still an option in Reg.134 for test type V (durability of pollution control devices), the position of the European Commission is to rapidly phase out the AMA because it is obsolete (not designed for modern engines, and working mainly at low to medium load) Clearly, the AMA's speed load points do not relate to the WMTC in terms of load. The Effect Study should provide a systematic study to confirm these points and suggest a reasonable date to phase out the AMA cycle and leave only the SRC.

7.6 Further Recommendations for the Euro 5 Effect Study

The full list of tasks to be covered by the Effect Study can be found in Appendix 2. In addition, the authors would like to give in the following some basic recommendations and guidelines for the Euro 5 Effect Study.

WMTC speed profile

We noticed that low-power vehicles such as mopeds might have problems in following the accelerations of the WMTC, especially at the beginning of the test when the engine is still cold. Nevertheless, we managed to overcome this situation by slightly anticipating the accelerations (1 to 2 seconds) without compromising the correct operation in idle before accelerating (no speed violations). Note that if the vehicle cannot follow the WMTC speed trace, it will likely have problems in following the speed trace of pre-Euro 5 driving cycles as well.

SRC cycle

It is clear that the SRC cycle resembles by design the load points of the WMTC. The Effect Study should contain a time plan and a cost-benefit analysis of the Test Type V (durability) to support the exclusion of the AMA cycle from type approval testing for the L-category.

ECU

The Effect Study should underline the need for all L-category vehicles to record and make easily available several parameters that are commonly logged in larger vehicles, e.g., engine speed, throttle position sensor, intake air flow, manifold absolute pressure, fuel injection timing, calculated load.

WMTC classes

Vehicles at the edge of classes 2-1 and 2-2 in the WMTC classification: It may happen that vehicles in this region of the classification map based on engine maximum speed and engine capacity will be subject to a lenient WMTC test cycle compared to a more severe pre-euro 5 (UNECE-R40 [3]) cycle. The Effect Study should confirm and elaborate on these occurrences.

References

[1] European Commission, 2013. Regulation (EU) No 168/2013 of the European Parliament and of the Council of 15 January 2013 on the approval and market surveillance of two- or three-wheel vehicles and quadricycles. Official Journal of the European Union, 2013, OJ L60.

[2] European Commission, 2014. Regulation (EU) No 134/2014 of 16 December 2013 supplementing Regulation (EU) No 168/2013 of the European Parliament and of the Council with regard to environmental and propulsion unit performance requirements and amending Annex V thereof. Official Journal of the European Union, 2014, OJ L53.

[3] United Nations, Regulation No. 40: UNIFORM PROVISIONS CONCERNING THE APPROVAL OF MOTORCYCLES EQUIPPED WITH A POSITIVE IGNITION ENGINE WITH REGARD TO THE EMISSION OF GASEOUS POLLUTANTS BY THE ENGINE. Available at: R40.

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[5] European Commission, 1970. Directive 70/220/EEC of 20 March 1970 on the approximation of the laws of the Member States relating to measures to be taken against air pollution by gases from positive-ignition engines of motor vehicles. Official Journal of the European Communities, OJ L76/1.

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[8] Giechaskiel, B., Zardini, A., and Martini, G., "Particle Emission Measurements from L-Category Vehicles," SAE Int. J. Engines 8(5):2015, doi:10.4271/2015-24-2512.

[9] Platt et al., "Two-stroke scooters are a dominant source of air pollution in many cities" 5:3749. Nature Communications, 2014.

Appendix 1: Administrative information

EUROPEAN COMMISSION
JOINT RESEARCH CENTRE

Institute for Energy and Transport
Sustainable Transport Unit

Ispra, 17 February 2016

PREPARATORY WORK FOR THE ENVIRONMENTAL EFFECT STUDY ON THE EURO 5 STEP OF L-CATEGORY VEHICLES

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CUSTOMER: DG-GROWTH

PROGRAM RESPONSIBILITY: DG-JRC

SERVICE REQUEST: ARES 2387593

ADMINISTRATIVE ARRANGEMENT: № SI2.694089

JRC PROJECT NUMBER: WP2015(A) - 2269

DELIVERABLES IN THIS REPORT:

(1a) The theoretical available engine load variables should be collected, assessed on pros and cons and if feasible selected to start the experimental programme.

(1b) An experimental test programme shall be conducted on 8 different test vehicles classified as category L so as to identify, verify and validate an appropriate engine load variable.

(1b.1) The above referred test cycles shall be specified according to Regulation (EU) No 134/2014[4];

[4] Commission Delegated Regulation (EU) No 134/2014 of 16 December 2013 supplementing Regulation (EU) No 168/2013 of the European Parliament and of the Council with regard to environmental and propulsion unit performance requirements and amending Annex V thereof. OJ L53, 21.2.2014, p1

(1b.2) The above test fleet shall in addition be tested under real world driving conditions and be tested on the chassis / engine dynamometer to determine maximum power and torque.

The test data shall be analysed and the preferred option shall be recommended for the engine load variable.

(1c) Plotting of engine speed vs engine load in scatter plots or similar and to determine the part-load area tested and sampled in the respective test cycles expressed as share of the maximum feasible operation range (maximum torque operation);

(1d) Literature study and contacting environmental performance test equipment suppliers to select appropriate environmental performance test equipment suitable to be fitted on (ultra-) light vehicles of category L;

Appendix 2: Structure of the Effect Study

The Euro 5 L-category Environmental Effects Study was the subject of an open Call for Tender the tasks of which are summarized below.

Tender reference number	465/PP/GRO/IMA/15/11825.
Title	Effect study of the environmental step Euro 5 for L-category vehicles.
Description	For the approval of an L-category vehicle, a number of environmental tests will need to be conducted among others and the test results shall be reported to the approval authority in order to validate that the environmental performance of a L-category vehicle type complies with the minimum requirements set out in Regulation (EU) No 168/2013 of the European Parliament and of the Council and its delegated and implementing acts, before it may be placed on the market and registered. In addition, the study will also assess the feasibility and cost-effectiveness of in-service conformity testing requirements, off-cycle emission requirements and a particulate number emission limit for certain (sub-) categories. On the basis of the study results, the Commission should consider presenting a proposal introducing these new elements into future type-approval legislation applicable after the stages foreseen in the current Regulation.
Contract type	Services
Procedure type	Open procedure

<u>Tasks in the Effect Study</u>

JRC is in charge of **Phase 1** of the Effect Study:

a. Stocktaking and data mining (type-approval data). Completed, soon available.

b. Public consultation (opinions from stakeholders and authorities). Completed[5], available at: http://publications.jrc.ec.europa.eu/repository/handle/JRC98900

c. Literature study. Completed, soon available.

A contractor is in charge of **Phase 2** and **Phase 3** of the Effect Study

Phase 2.1: Experimental assessment and verification programme of measures within the Euro 5 environmental step as mandated by Article 23 (4) and (5).
Task 2.1.1.: Assessment Type I - Tailpipe emissions test after cold start.

[5] JRC Science for Policy Report: Views on the Implementation of the Euro 5 Environmental Step for L-Category Vehicles, see References.

Sub-task 2.1.1.1: Assessment of the applicability of the WMTC (Worldwide harmonized Motorcycle Testing Cycle)to all the L-category vehicle types laid down in Regulation (EU) No 168/2013 and as supplemented by Regulation (EU) No 134/2014.
Sub-task 2.1.1.2: Assessment of the appropriateness of the Euro 5 tailpipe emission limits laid down in Annex VI(A) of Regulation (EU) No 168/2013.
Sub-task 2. 1.1.3: Assessment of the separate NMHC limit
Sub-task 2.1.1.4: Assessment of the impact of ethanol in the reference fuel on the test type I results.
Task 2.1.2: Assessment Type II – Tailpipe emissions at (increased) idle and free acceleration.
Task 2.1.3: Assessment Type III – Emissions of crankcase gases.
Task 2.1.4: Assessment Type IV – Evaporative emissions test.
Sub-task 2.1.4.1: Assessment of evaporative emission test procedures set out in Annex V to Regulation (EU) No 134/2014, in particular the permeation and SHED test procedures.
Sub-task 2.1.4.2: Investigation of the cost effectiveness of a 25% lower Euro 5 evaporative emission limit compared to the Euro 4 limit for vehicles subject to the SHED test.
Sub-task 2.1.4.3: Investigation of the impact of fuel quality on the evolution of fuel permeation rate over time as well as the ageing effects of the carbon canister.
Sub-task 2.1.5.1: Validation of distance accumulation cycle (SRC-LeCV).
Sub-task 2.1.5.2: Validation of assigned Deterioration Factors and useful life values.
Task 2.1.6: Assessment Type VII – Energy efficiency tests (CO_2 emissions, fuel/energy consumption and electric range measurements).
Task 2.1.7: Assessment functional on-board diagnostics requirements and Type VIII – OBD environmental tests + background information.
Sub-task 2.1.7.1 - On-board diagnostic requirements – expansion functionality OBD stage I to OBD stage II – relevance for effective and efficient vehicle repair.
Sub-task 2.1.7.2: Type VIII test - assessment of the OBD emission thresholds (OTLs) set out in the table laid down in Annex VI(B2) to Regulation (EU) No 168/2013.
Sub-task 2.1.7.3 - On-board diagnostic requirements – assessment of the cumulative cost effectiveness of sub-tasks 1.7.1. and 1.7.2. and technical feasibility of supplemental OBD stage II.

Phase 2.2: Research and assessment of the elements listed in recital 12 of Regulation (EU) No 168/2013 (beyond the Euro 5 step).
Task 2.2.1: Off-cycle emissions testing.
Sub-task 2.2.1.1. Experimental test programme on technical feasibility off-cycle emission requirements.
Sub-task 2.2.2.2.Benefit / cost ratio range and cost effectiveness analysis off-cycle emission requirements.
Task 2.2.2: In-service conformity verification testing.
Task 2.2.3: Assessment of the need to expand the PM limit scope to other vehicle categories than those already subject in the Euro 5 step and introduction of a PN limit

Phase 3: Validation programme and final report.

List of abbreviations and definitions

A/F	Air-Fuel ratio
CO	Carbon monoxide gas
CO_2	Carbon dioxide gas
CVS	Constant Volume Sampler
ECU	Engine Control Unit
ETC	Electronic Throttle Control
GPS	Global Positioning System
I/O	Input / Output
L-cat	Light category vehicles (L-category)
MAF	Mass Air Flowmeter
MAP	Manifold Absolute Pressure
NDIR	Non-Dispersive Infrared analyser
NO	Nitric oxide gas
NO2	Nitric dioxide gas
NOx	Nitric oxides gases
O2:	Oxygen gas
PEMS	Portable Emission Measurement System
PM	Particulate Mass
PN	Particle Number
THC	Total Hydrocarbons
RPM	Engine speed (revolutions per minutes)
WMTC	Worldwide harmonized Motorcycle driving Cycle
WOT	Wide Open Throttle (max power) driving cycle

Pre-Study: input to the Euro 5 L-category Effect Study (present study)

Effect Study: Euro 5 L-category Environmental Effects Study

Reg.168: Regulation (EU) No 168/2013

Reg.134: Regulation (EU) No 134/2014

R40: UNECE-R40 driving cycle as detailed in UN Regulation No. 40

R47: UNECE-R47 driving cycle as detailed in UN Regulation No. 47

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